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RECOVERY OF RADIOACTIVE IODINE AND STRONTIUM FROM HUMAN URINE--OPERATION TEAPOT (U)

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Walter Reed Army Medical Center
Washington 12, D.C.

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AFSWP-893

WRAIR-1S-55

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Project: 6-59-08-014, Biological and Medical Aspects of Ionizing Radiation
Subtask No. 16: World-wide Contamination (Interim Report)

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WRAIR-1S-55
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Subtask No. 16

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RECOVERY OF RADIOACTIVE IODINE AND STRONTIUM FROM HUMAN URINE—OPERATION TEAPOT (U)

ABSTRACT

During Operation Teapot, 2,137 human urine specimens from a number of United States and foreign military stations were analyzed for iodine-131 and strontium-90 activity. Special processing and counting technics designed to measure low-level activities were utilized. A number of samples were found to contain radioactive iodine and strontium. An attempt was made to correlate urinary iodine activity with weather-yield and physical fallout data. Certain biological aspects of the problem are discussed and compared to theoretical models.

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RECOVERY OF RADIOACTIVE IODINE AND STRONTIUM FROM HUMAN URINE--OPERATION TEAPOT (S)

I. Introduction

This study was initiated to determine the variation of urinary excretion of certain fission materials by human subjects during the period required for atomic weapons testing at Operation Teapot. Because of the small yields of these particular test weapons, limited positive data were expected. The study was designed to provide base line information for the spring 1956 tests in the Pacific in which the yields are expected to be considerably greater. This report is concerned with the detection of radioactive iodine-131 and strontium-90. Previous experience at weapons tests with urinary excretion of fission materials by human subjects is reported by Cronkite et al. (1), Brennan et al. (2) and Thomas (3). The latter reports deal with individuals up to 8,000 miles from the test site. This report concerns itself primarily with an acute exposure problem as contrasted to the work by Larson (4) and others relating to the concentration of activity by plants and animals and their subsequent ingestion by man.

OPERATIO REDWIN

II. Methods

15 17

The collection process included selection of ten individuals from each of several United States stations, and a minimum of five subjects from each overseas area. Stations were selected with a view toward reasonable coverage of the United States and a limited sampling throughout the world. To expedite collection and shipment of specimens, the larger military installations were utilized wherever possible. Figures 1 and 2 indicate the location of stations. Operation Teapot Weapons Data are listed in Table A.

An attempt was made to utilize, insofar as possible, the same healthy adult male persons for the entire period of the study and to exclude any with a history of thyroid disease or previous known exposure to radioactive materials. Twenty-four-hour urine collections were scheduled to begin at 0800 each Tuesday and to continue at weekly

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(1) Armed Forces Special Weapons Project ITR-923 - May 1954 (Secret).

(2) Report of Project 1-M-54 on Thirty Service Men Exposed to Residual Radiation at Operation Castle and Supplement to Project 1-M-54 - July 1954. Brennan et al. (Secret).

(3) Analytical Report of Radioactive Substances in Special Urine Samples - C. W. Thomas and D. C. Linton - General Electric Co., Richland, Washington (Confidential).

(4) Armed Forces Special Weapons Project WT-812 (Confidential).

[redacted]

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intervals beginning 25 January 1955. Final collection was made 24 May 1955. Specimens collected prior to 18 February 1955 were to serve as the pre-test controls. All samples were shipped by air to the Army Medical Service Graduate School (former name of Walter Reed Army Institute of Research), Walter Reed Army Medical Center, Washington 12, D.C., for analysis.

SEE Pg. 5

Table A

Shot Data* For Operation Teapot

Date	Yield	F.B.R.**	Type	Height
18 Feb.	1.2	150	Air drop	755 ft.
22 Feb.	2.5	220	Tower	300 ft.
1 Mar.	7	320	Tower	300 ft.
7 Mar.	43	650	Tower	500 ft.
12 Mar.	3.6	250	Tower	300 ft.
22 Mar.	8.1	340	Tower	500 ft.
23 Mar.	1.2	150	Underground	67 ft.
29 Mar.	15	460	Tower	500 ft.
29 Mar.	3.1	250	Air drop	750 ft.
6 April	3.1	250	Air drop	36,000 ft.
9 April	1.5	200	Tower	300 ft.
15 April	24	560	Tower	400 ft.
5 May	30.0	600	Tower	500 ft.
15 May	30.0	600	Tower	500 ft.
	172.5 series total			

*From ITR-1153, Summary Report of Technical Director, June 1955.
**Fire Ball Radius in feet.

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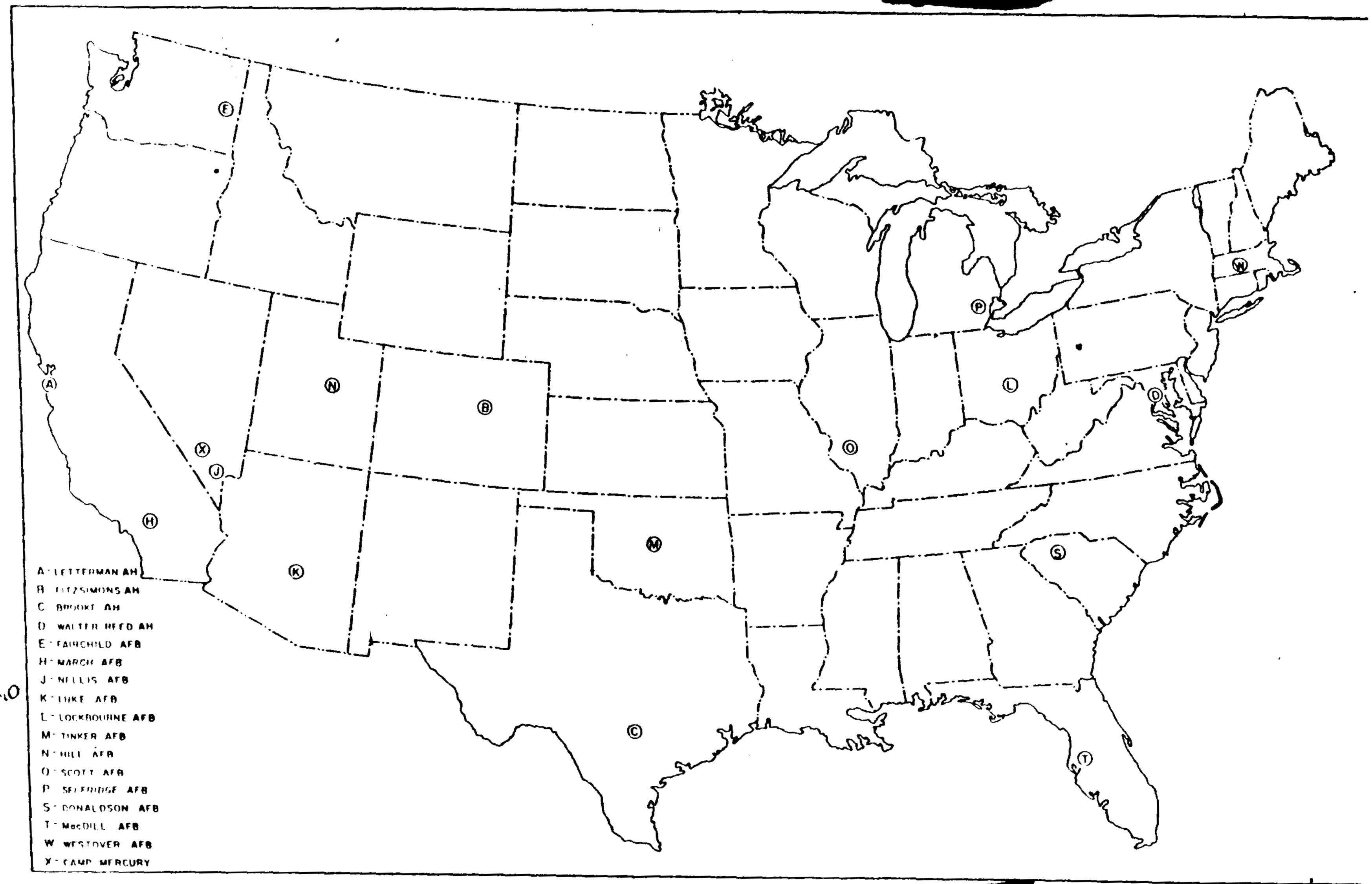
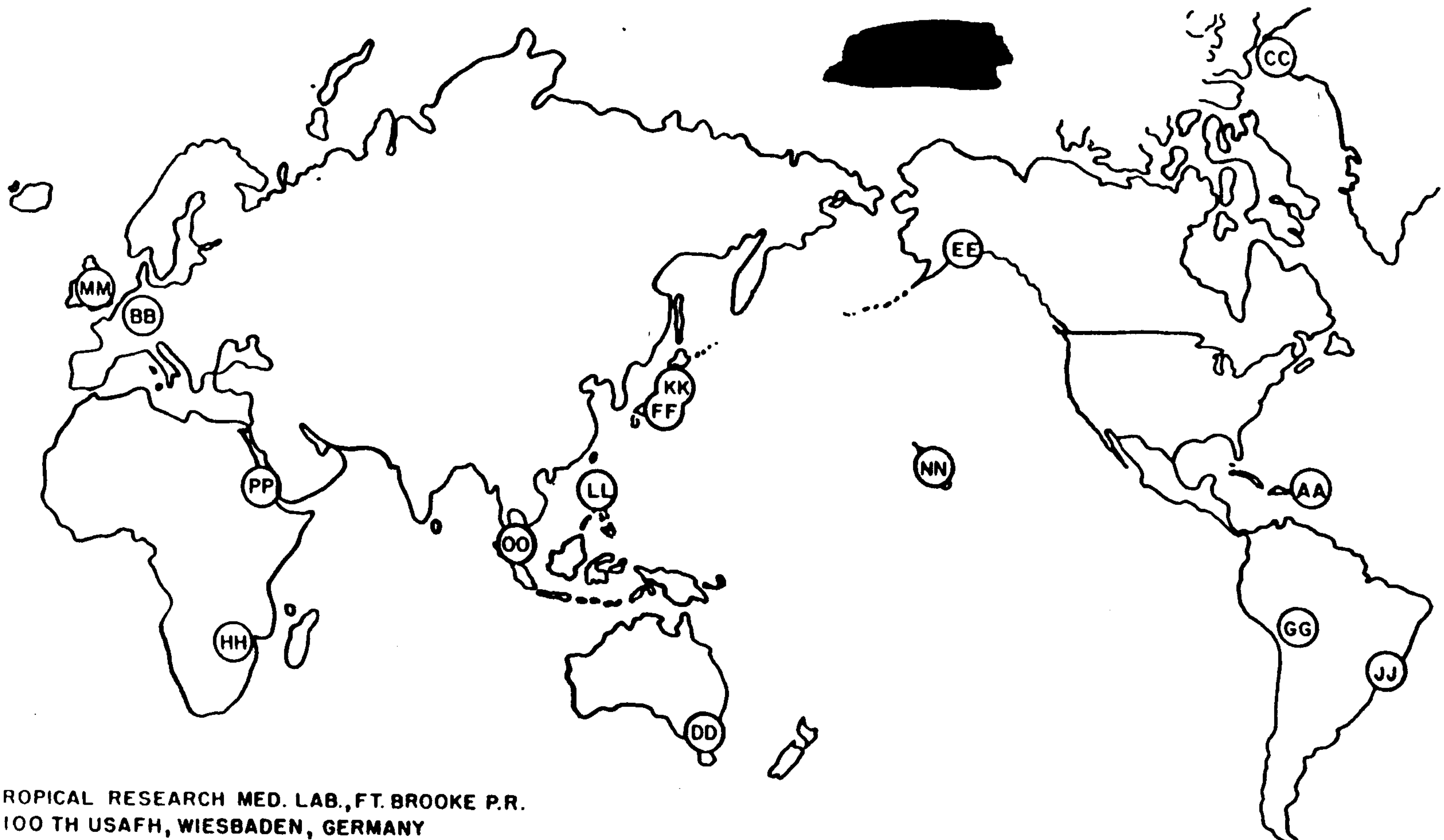


FIG I MAP OF US COLLECTION STATIONS

(17)

A + C
↓
HUMAN THYROID GLAND(S)
TIME OF ROUTINE AUTOPSY

[redacted]



AA – TROPICAL RESEARCH MED. LAB., FT. BROOKE P.R.
BB – 7100 TH USAFH, WIESBADEN, GERMANY
CC – 6607 TH USAFH, THULE, GREENLAND
DD – USAIRA, MELBOURNE, AUSTRALIA
EE – USARAL, FT. RICHARDSON, ALASKA
FF – 406 TH MED. GEN. LAB., TOKYO, JAPAN
GG – USA MISSION TO BOLIVIA, LA PAS, BOLIVIA
HH — USAIRA, PRETORIA, UNION OF SOUTH AFRICA
JJ — US ARMY SECTION, JBUMSC, RIO DE JANIERO, BRAZIL
KK — 6000TH USAF DISP., KYO, JAPAN
LL — 6208TH USAFH, LUZON, P.I.
MM — 7559TH AIR DEP. WG., BURTONWOOD, ENGLAND
NN — TRIPLER AH, T.H.
OO — US ARMY MED. RESEARCH UNIT, KUALA LUMPUR, MALAYA
PP — KAGNEW STA., ASMARA, ERITREA

FIG. 2 MAP OF STATIONS FOR WORLD COLLECTION [redacted]

[redacted]

To supplement the data obtained in examination of the urine samples for iodine, arrangements were made through the Armed Forces Institute of Pathology for collection of human thyroid glands. These glands were removed at the time of routine autopsy at Brooke Army Medical Center and Letterman Army Hospital. Cases of known thyroid disease or those having received isotope materials within the last year of life were to be excluded.

46 THYROID GLANDS EXAMINED

Details of extraction and counting procedures for urinary iodine-131 are recorded in detail in Appendix B-1. Details of processing and counting procedures for the thyroid glands are recorded in Appendix B-2.

Estimates of the amount of strontium-90 to be encountered were of such a low order of magnitude that it was necessary to combine several 24-hour specimens from a given station for a given week. Usually the specimens were pooled for several weeks. The details of extraction and counting procedures for strontium-90 are recorded in Appendix B-3.

III. Results and Discussion

Iodine. The complete data from United States stations for the period of the operation are listed in tabular form in Appendix A, Tables 1-17. A total of 2,137 individual specimens were processed. Individual values are recorded for each week and represent activity of a 24-hour urine collection. The disintegrations per minute (dpm) are corrected to time of collection of the sample. It should be noted that samples prior to 22 February are not recorded. These were not included because of possible inadvertant laboratory contamination (See Appendix B-1). However, communication with the New York Operations Office, Atomic Energy Commission, indicated the presence of gross fission material at some of their stations in the weeks prior to 22 February. Further, analysis of data from one reactor (Hanford)* indicated that relatively large amounts of iodine-131 were exhausted from the stacks during this period. The procedures used in this project are of such sensitivity that detectable amounts of activity could have been due to reactor effluents.

∴ NO PRE-TEST CONTROLS

All specimens from foreign stations were essentially negative for iodine-131. However, considering the prolonged time (several half-lives) between collection and receipt of specimens, small amounts of activity originally present would have been undetectable.

NOT INCLUDED IN TABLES

If one considers individual specimens from a single station on any one collection date, it is apparent that there is a marked variation between individuals. The most active sample may contain more than 10 times the activity of the least active sample. Larger variations occurred at stations close to Camp Mercury and the variation between samples generally diminished as the distance of the collection

*Health and Safety HW-36506 (Secret -- Restricted Data)

[redacted]

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[redacted]

station from the detonation site increased. Even so, it was not uncommon to find a few samples that differ by a factor of five or six in distant stations. The 24-hour urine showing the highest activity of any specimen assayed was from Camp Mercury, Nevada. The urine contained an iodine activity of 774 dpm corrected to date of collection. Therefore, 3.5×10^{-4} microcuries of iodine-131 were excreted by this individual over the 24-hour collection period.

An interesting decay curve was obtained from a Camp Mercury sample which was first assayed 2 days after collection. The curve demonstrated the presence of iodine-133 as well as iodine-131 (Fig.3). The presence of this very short half-life isotope (23 hours) strongly implicates inhalation as an important route of entry for man.

In analyzing the data from stations showing appreciable amounts of activity, certain practical factors were considered. These included an attempt to correlate bomb yield and weather trajectories for a particular detonation with physical fallout measurements as obtained by Eisenbud* and by iodine excretion in the urine. Such correlation of physical and biological factors, combined with known or estimated weather and weapon data, would have obvious operational significance.

Presentation of the above-mentioned parameters was facilitated by the construction of Figures 4 through 9. The material incorporated in these figures was obtained in the following manner:

a. Iodine activity: Each value in the bar graphs represents the mean dpm for all individual 24-hour samples collected from the specified station on the indicated date. The mean value was selected as representative of the relatively acute environmental exposure and subsequent urinary excretion of iodine for an "average" individual. Variations in activity as noted in Appendix A, Tables 1-17, in general reflect biological factors such as the amount of respiratory exchange for 24 hours (dependent primarily on physical activity) and the several variables influencing uptake of iodine by the thyroid gland. It is assumed that the environmental exposure was the same for all individuals at a single station.

b. Cloud trajectory information was obtained from maps drawn for each shot by the U. S. Weather Bureau.** Cloud altitudes are those used most frequently on available Weather Bureau maps. Any given X designates the presence of the cloud over the station at specified altitude and date.

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*Physical fallout data obtained from New York Operations Office, Atomic Energy Commission, by Eisenbud and Harley. These data were collected using standardized fly paper technic and represent gross fission product activity exclusive of iodine and other volatile elements.

**Cooperation of Dr. A. Machta is gratefully acknowledged.

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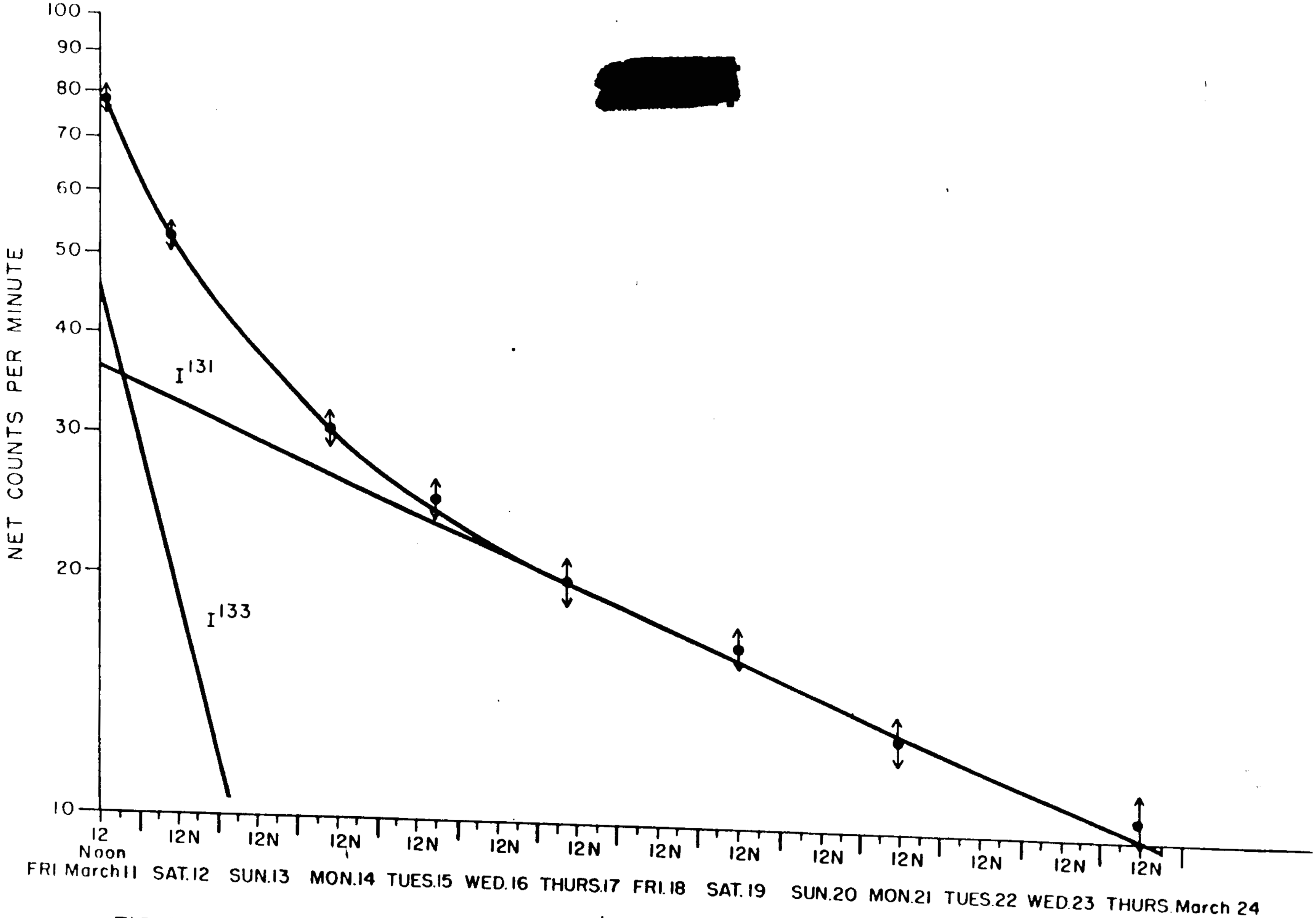

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FIG. 3 DECAY CURVE DEMONSTRATING THE PRESENCE OF BOTH I^{131} AND I^{133}

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FIGURE 4

FITZSIMONS ARMY HOSPITAL
DENVER, COLORADO (B)

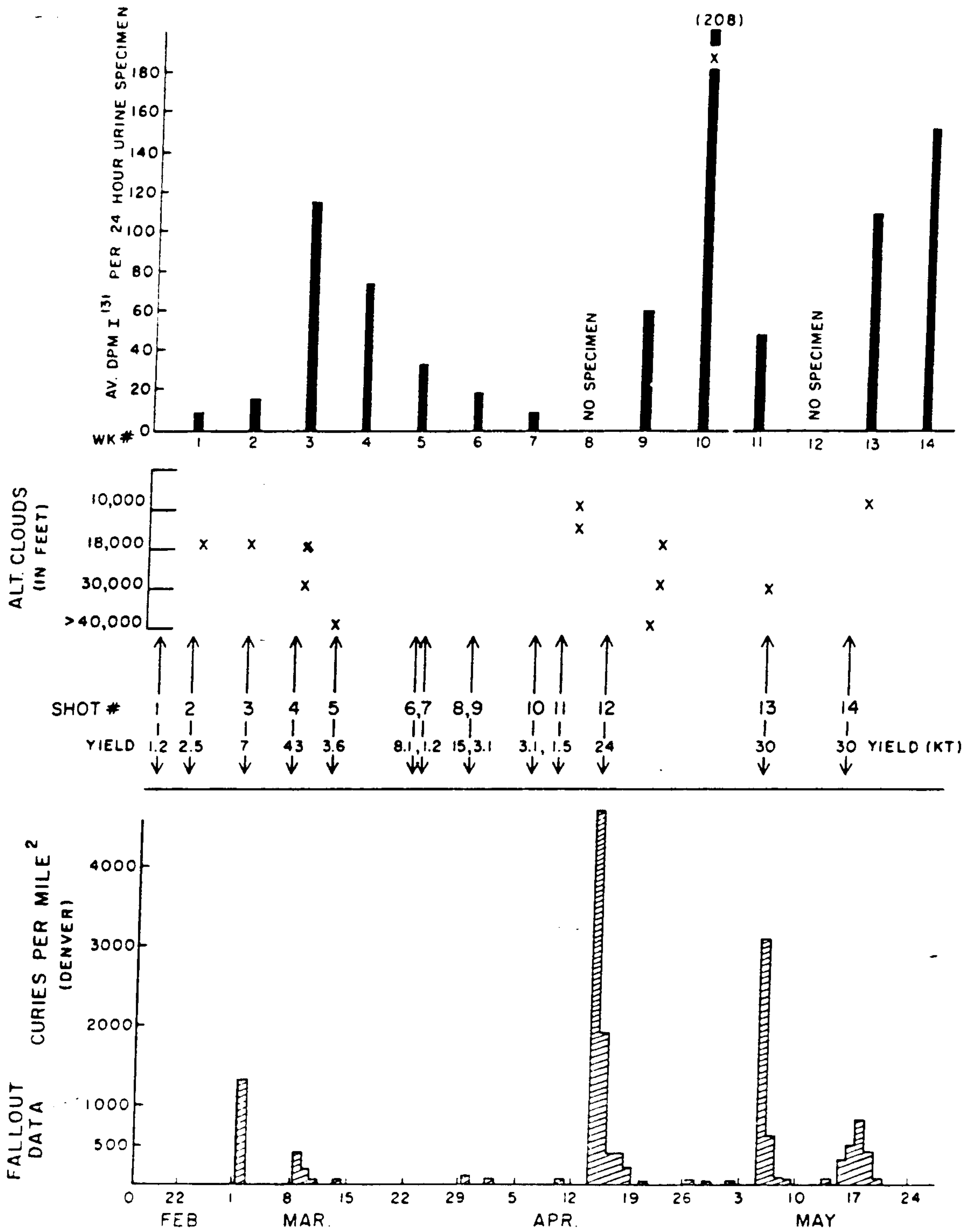

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FIGURE 5

WALTER REED ARMY MEDICAL CENTER
WASHINGTON, D.C. (D)

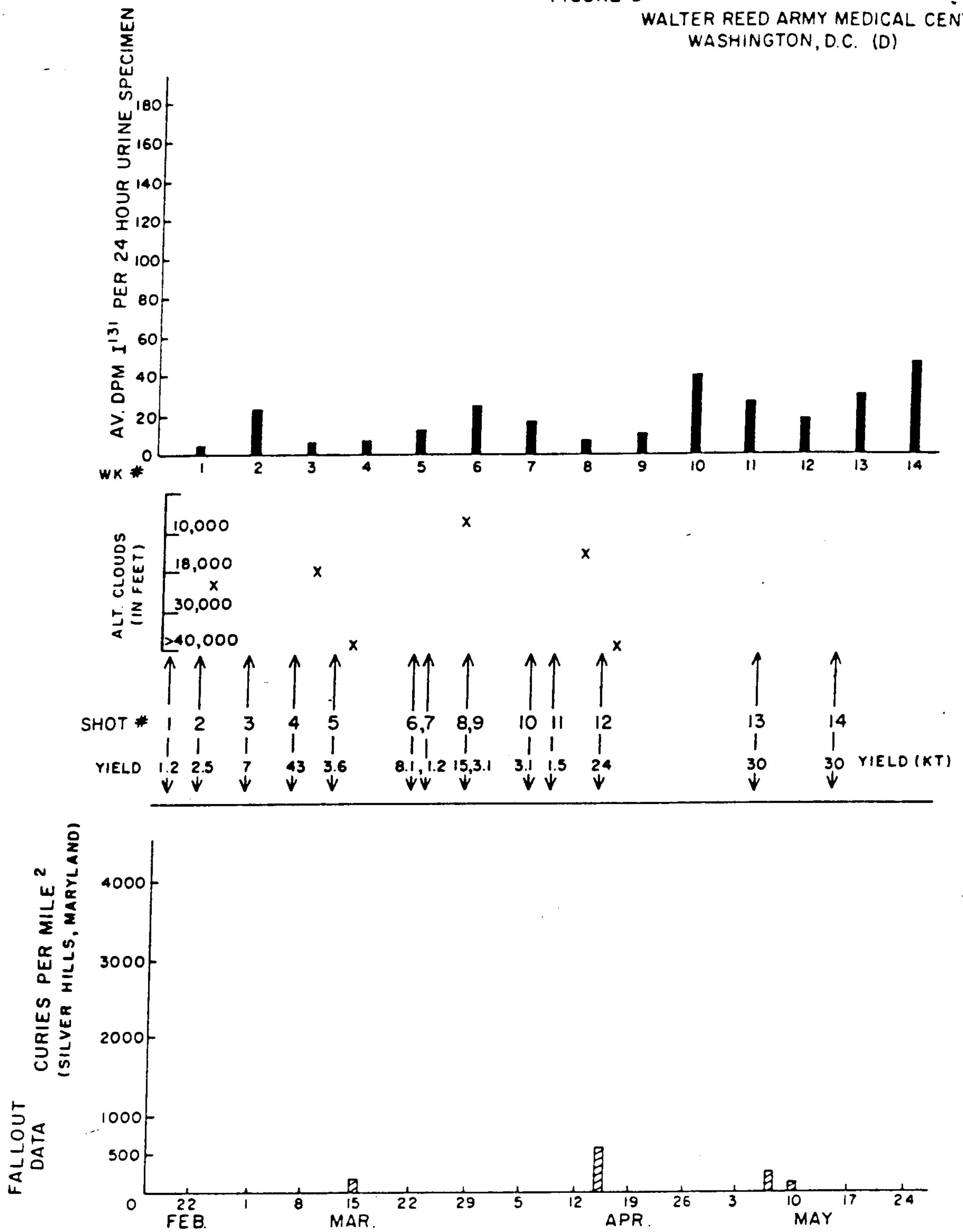

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FIGURE 6

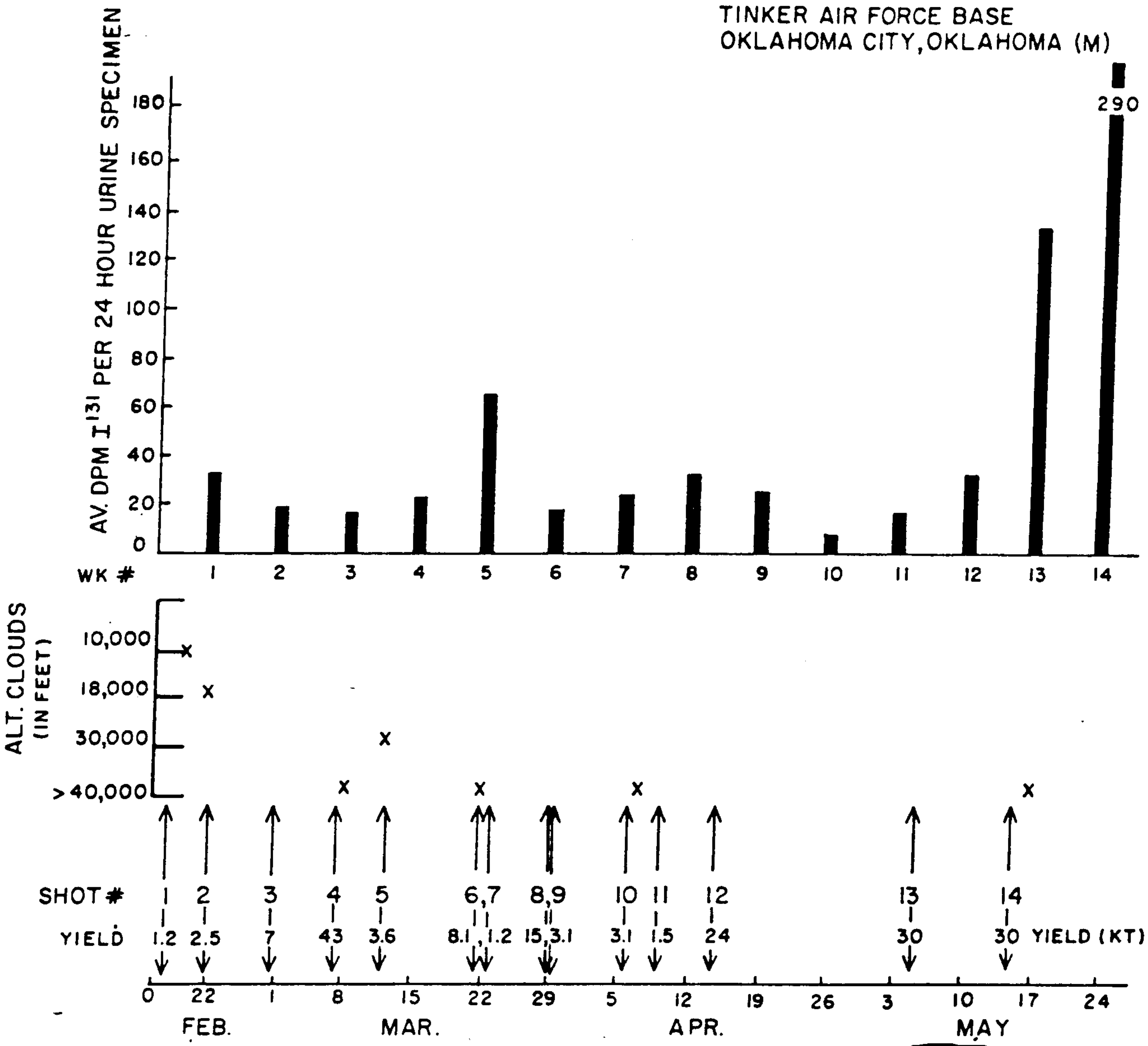

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FIGURE 7

HILL AIR FORCE BASE
OGDEN, UTAH (N)

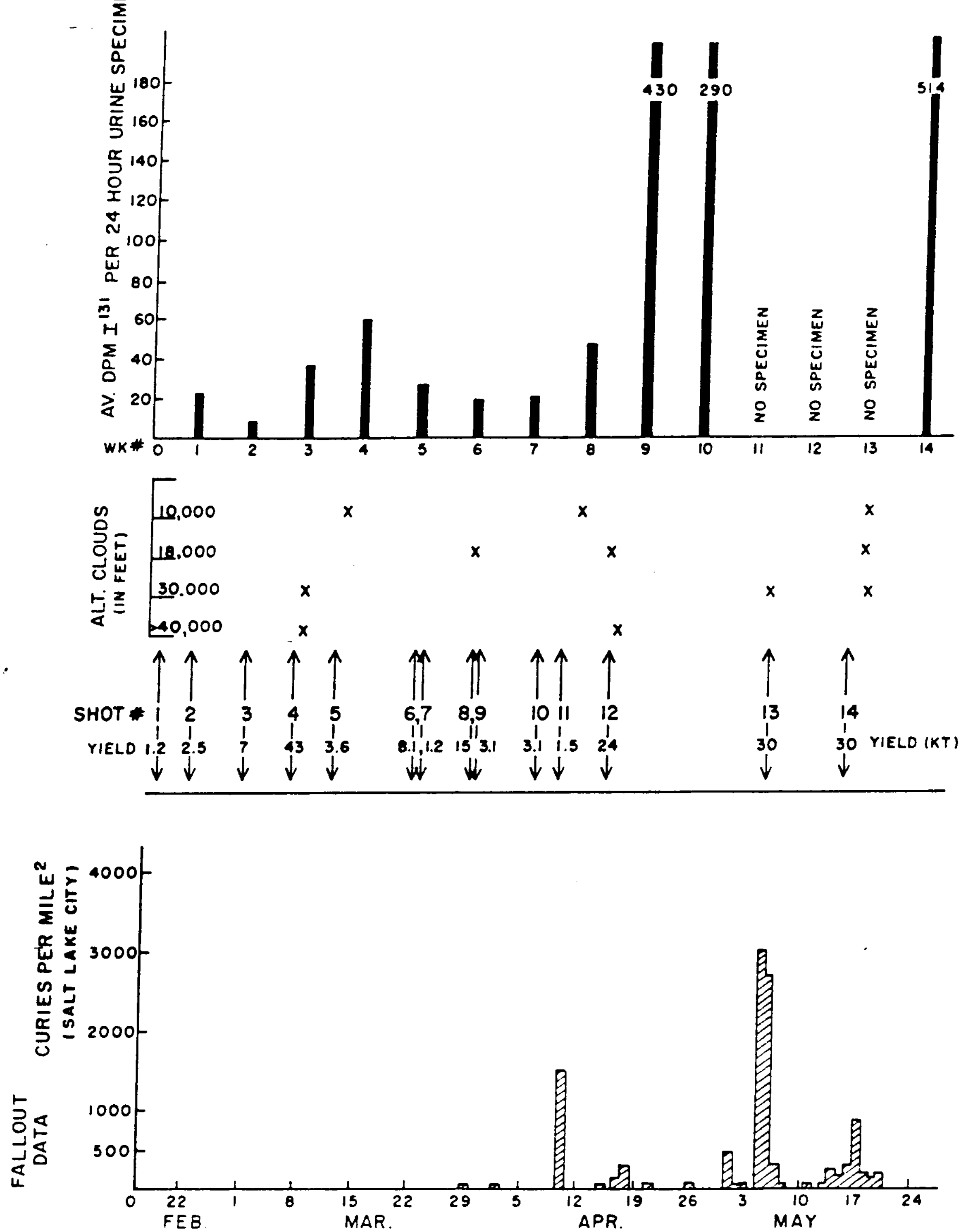

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FIGURE 8

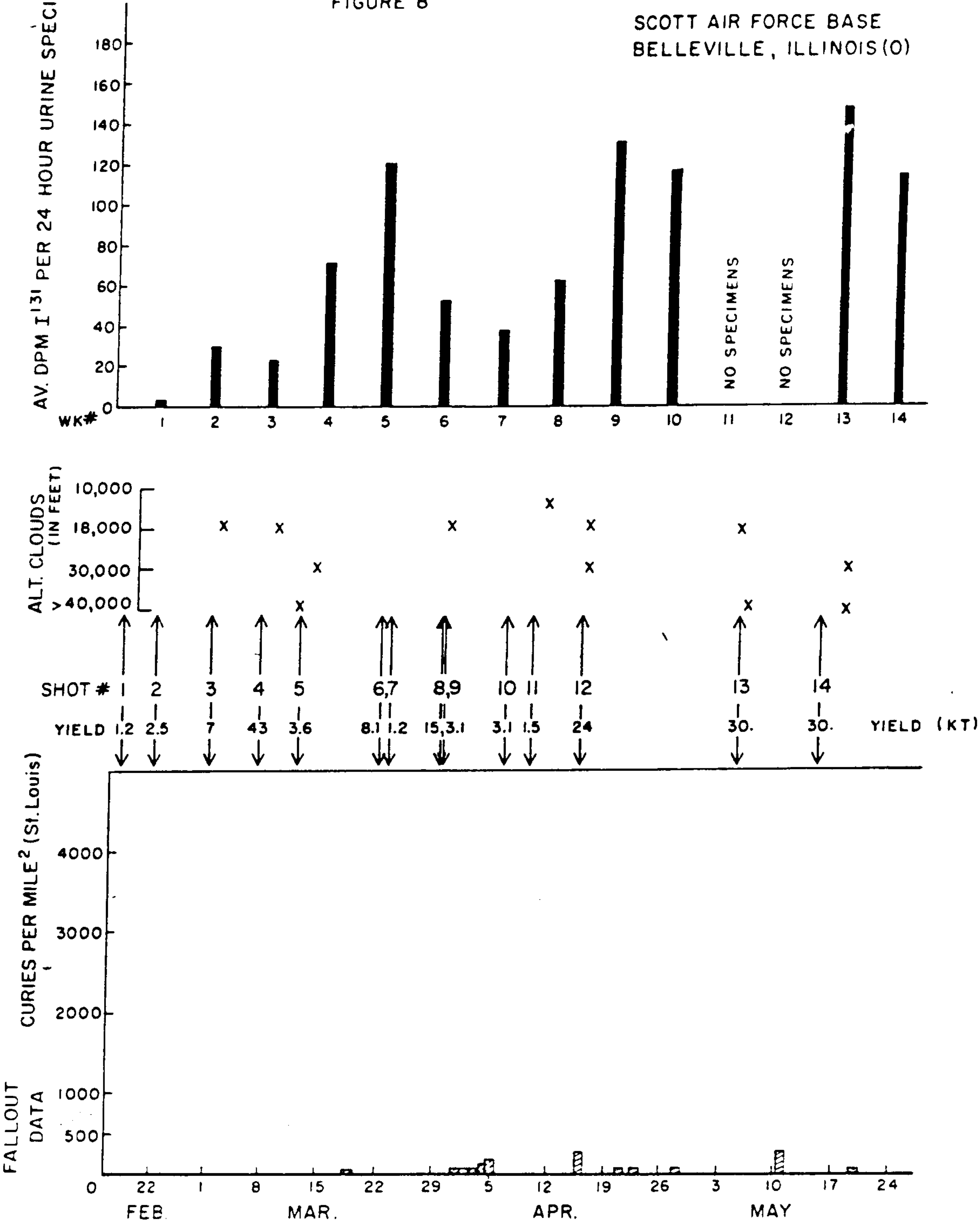

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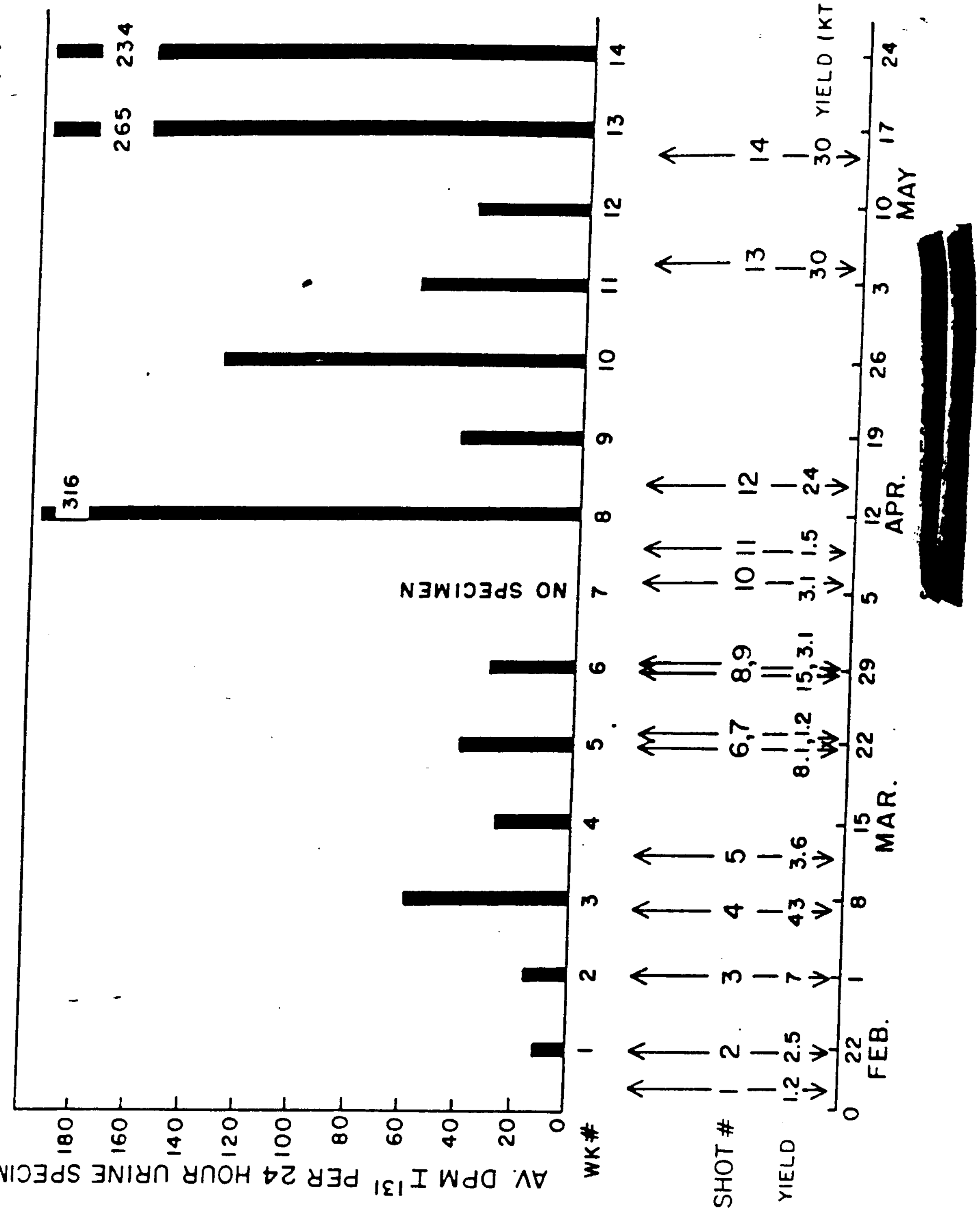
FIGURE 9
CAMP MERCURY, NEVADA (X)



[redacted]

c. Shot dates and yields are as indicated.

d. Physical fallout data were obtained from Eisenbud and are represented as curies per square mile of gross fission activity. It is emphasized that these values do not include iodine activity. Moreover, in most cases, the data were collected on a daily basis; therefore, the absence of a bar does not imply zero activity, but rather that the amounts were less than 50 curies per square mile.

The data presented in Figures 4 through 9 would appear to demonstrate:

a. Reasonably good correlation between the combined weather-yield data and iodine excretion. The passage of the cloud is in most cases followed by elevated iodine levels and larger rises usually follow clouds produced by shots of higher yields. The validity of this correlation is strengthened when one considers the converse of the above; namely, absence of clouds generally accompanies low iodine levels.

b. There is an apparent lack of correlation between the combined weather-yield data and physical fallout measurements. This cannot be explained at this time.

c. There is an apparent lack of correlation between urinary iodine and physical fallout measurements. This implies that the physical measurements, as currently determined, do not reflect the total biological hazard.

These attempts at correlation of the various factors are admittedly incomplete and are based on data which in fact measure different isotopes, namely, iodine and gross fission activity exclusive of iodine. Since there is no known evidence of significant iodine fractionation or separation from total fission activity, it was thought that the physical and biological measurements do represent part of the same problem and therefore should correlate generally with weather-weapon data.

Estimation of Biological Hazard. An accurate calculation of radiation dosage to the thyroid (the critical organ for iodine) obviously cannot be made from weekly determination of the urinary activity. However, it is believed that an estimate of exposure to an "average" individual at a given station may be useful, particularly for a comparison with maximum permissible exposure levels referable to currently accepted medical concepts, and with values previously referred to as measured by Cronkite and Brennan in connection with Operation Castle.

The estimate of total thyroid dose was made according to calculations presented in detail in Appendix C-1. For the "average" individual at Fitzsimons Army Hospital, Figure 4, an integrated total of 0.011 roentgen equivalent physical (rep) was delivered to the thyroid throughout the entire test period. This may be compared to an integrated

[redacted]

[redacted]

total of 24 rep from a 10-microcurie tracer dose as commonly utilized in medical clinics. A 33 per cent uptake by the gland is assumed.

Thyroid Glands

Of the 46 thyroid glands examined, only two showed appreciable activity above background. One thyroid from a patient who had been living in Chicago showed some 0.2 microcurie on 15 June and a second thyroid showed an activity of 0.005 microcurie on 30 June. The decay of these samples was followed to definitely establish the identity of the activity as iodine-131. Correspondence disclosed that the Chicago patient received 45.9 microcuries of iodine-131 on 31 May 1955 and death occurred 1 June 1955. The Letterman Army Hospital patient was a retired soldier who returned to the hospital only during his terminal illness. No accurate record to establish isotope therapy in this case over the 9-month period preceding death is available. There was no record of radioactive iodine during his terminal illness.

Background Variation

A comparison of background count and iodine recovery from samples collected at Walter Reed Army Hospital, Washington, D.C. is shown in Figure 10. The initial level of urinary activity, i.e., less than 2 counts per minute, is within the error resulting from counting periods necessarily of short duration. The general correlation is apparent. During the period 8 February through 24 May a standard potassium-40 sample maintained a stable counting rate above background. This is very suggestive of air contamination and, in part, supports the thesis that in man inhalation is an important route of entry for fission products.

Strontium-90

The strontium activity measured in the combined urine specimens is indeed low. The processing methods used permit the measurement of 2 dpm of yttrium-90 (strontium-90). This represents approximately 1×10^{-6} microcuries. Values obtained which might be considered maximum apply to the total urinary excretion for the "average" individual during the entire test series:

Scott Air Force Base (Belleville, Illinois)	30×10^{-6} microcuries
Fitzsimons Army Hospital (Denver, Colorado)	24×10^{-6} microcuries
Tinker Air Force Base (Oklahoma City, Oklahoma)	30×10^{-6} microcuries

These figures are considered conservative with respect to hazard since samples which contained greater than average iodine activity were processed. Details of this calculation and additional values for strontium-90 are noted in Appendix C-2, Table 1. During the decay studies, the presence of other relatively long half-lived isotopes was noted, but these were not identified. The activity about equaled that of the strontium. Subsequent re-milking removed these isotopes.

SEE APPENDIX B-3
PG 2

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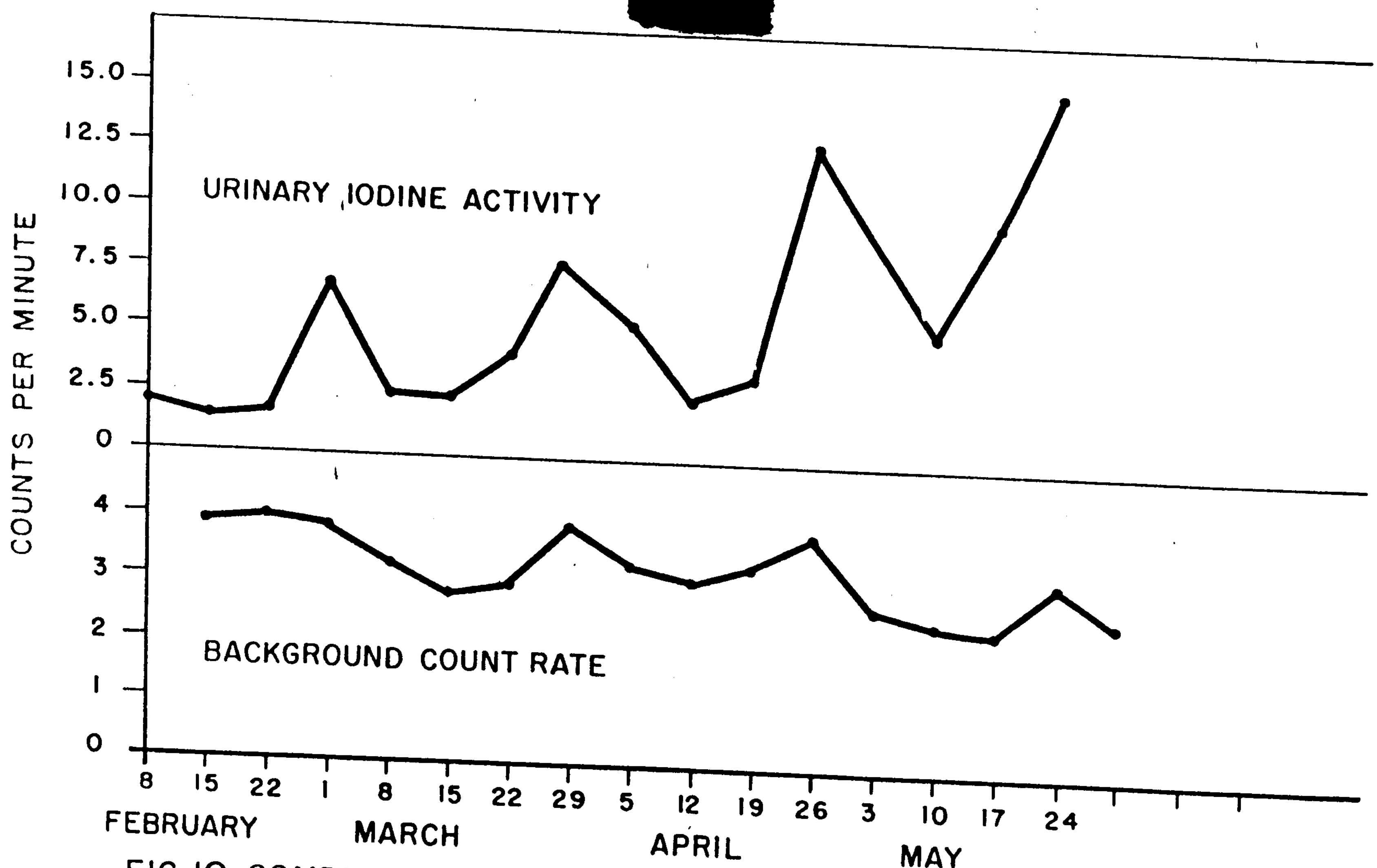

FIG. 10 COMPARISON OF BACKGROUND COUNT AND IODINE RECOVERY AT WALTER REED ARMY HOSPITAL

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Relationship Between Strontium and Iodine

A comparison of iodine and strontium excretion as measured in urine was undertaken to ascertain whether any functional relationship indeed prevailed. We were prompted to make this comparison when the data established the presence of higher amounts of strontium when higher amounts of iodine were found. There are no known data available for man relating to an acute strontium exposure problem such as that available for iodine-131 where inhalation is considered a primary route of entry.

The data in Figure 11 illustrate actual observations for iodine versus strontium in the same pooled specimens. The activity of iodine has been corrected in Figure 12 to time of detonation relating each component of the pooled specimen to a specific shot and subsequent cloud passage over the station. The accuracy of weather data for a specific shot limits the confidence in a precise correction factor. These decay-corrected data appear to define a reasonably direct relationship between iodine and strontium. The practical considerations implied by this statement require further verification and delineation at future nuclear tests.

In order to evaluate the measured levels of iodine versus strontium activity, a theoretical approach was used. If one accepts the assumptions that strontium and iodine are produced in essentially equal mass amounts at the time of fission, and that the intake and excretion components in man for these elements are essentially the same for an acute exposure, then the amounts of each isotope expected in the urine can be calculated.

The biology of strontium is not known for man; however, gross iodine kinetics are well established. Available excretion and retention data from animals* suggest that urinary strontium and iodine kinetics are somewhat analogous. Therefore, it is perhaps not unreasonable to expect that for a given ratio these isotopes would appear in essentially the same ratio in the urine.

Based on the above, it is calculated that 750 dpm of iodine should be expected for each dpm of strontium. Measured values give an average iodine to strontium ratio of 576, as determined by the "best drawn" line of Figure 12. Considering the approximations required for the derivation of the theoretical ratio, as outlined in Appendix C-3, there is excellent agreement between the calculated values and those actually measured.

In fact, the data indicate that somewhat more strontium was found than would be expected. The apparent, although not verified, explanation is that additional strontium was available through ingestion.

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*"Biological Hazards of Radioactive Strontium" by Vaughn in Biological Hazards of Atomic Energy by Haddow - Oxford 1952.

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FIGURE 11

RELATIONSHIP BETWEEN I^{131} AND Sr^{90} ACTIVITY — (UNCORRECTED DATA FOR POOLED SPECIMENS BY WEEKS AND STATIONS)

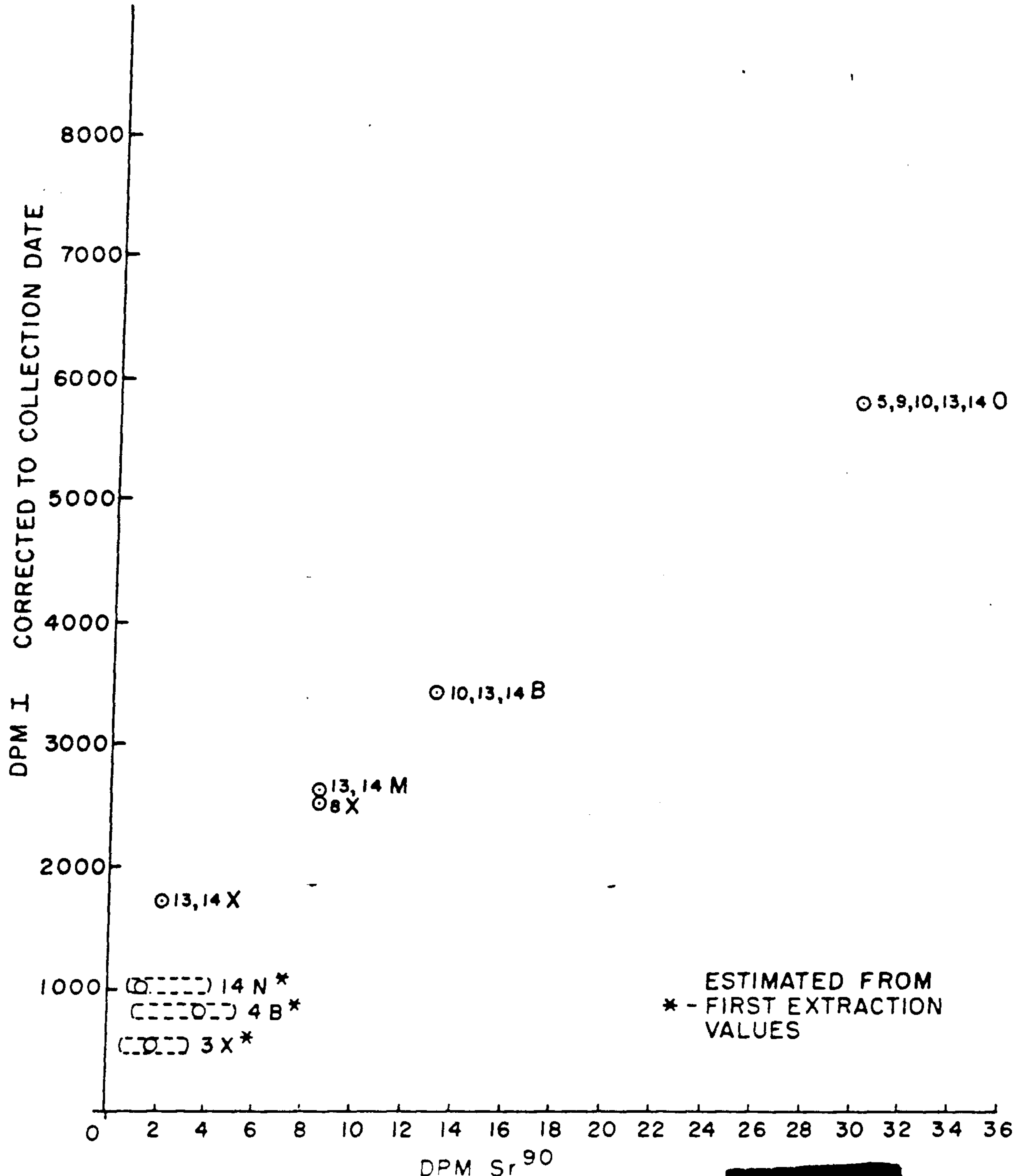

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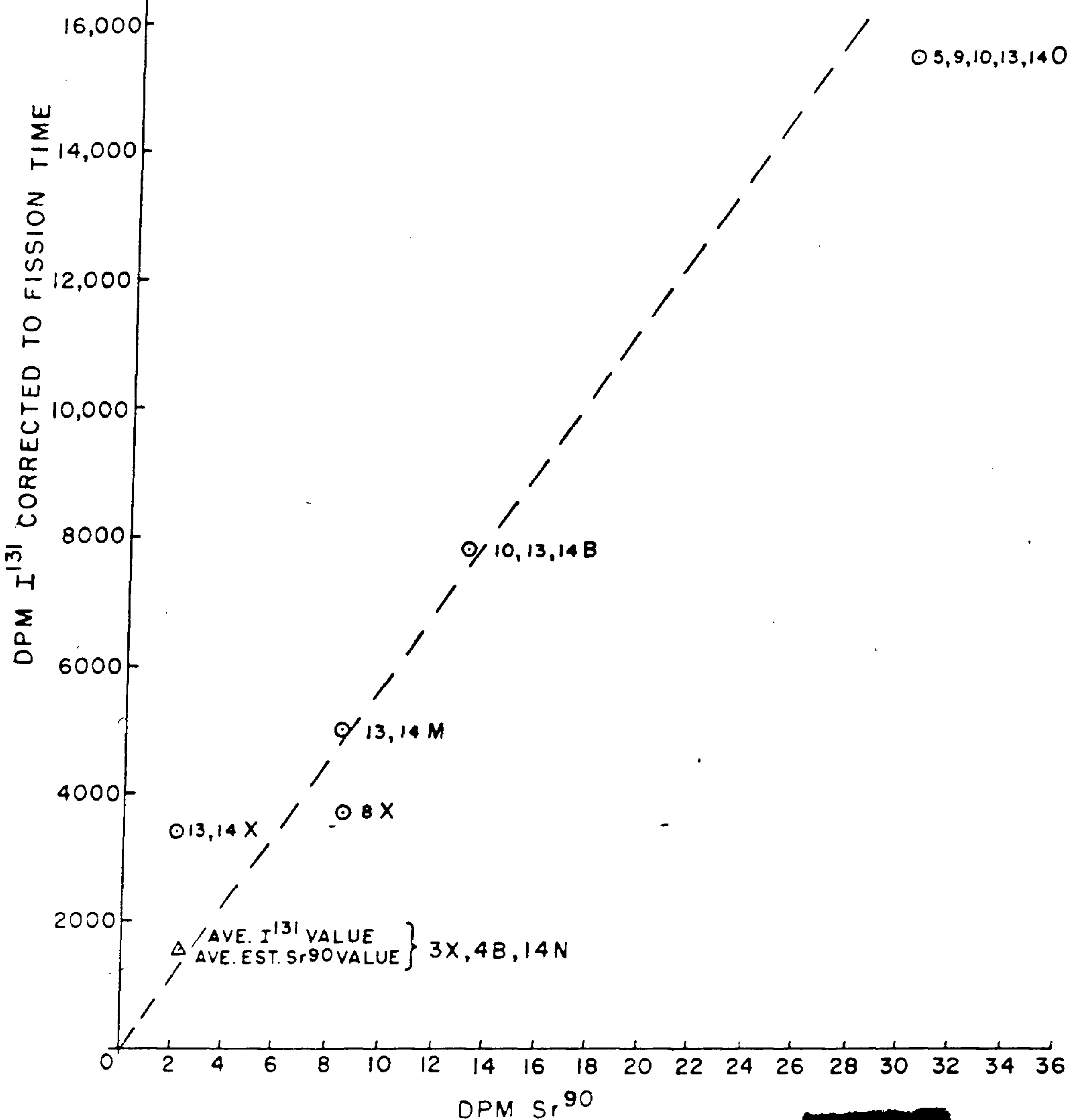
FIGURE 12

RELATIONSHIP BETWEEN I^{131} AND Sr^{90} ACTIVITY
(CORRECTED DATA FOR POOLED SPECIMENS
BY WEEKS AND STATIONS)



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IV. Conclusions

The practicability of conducting a world-wide human sampling program for urinary iodine-131 and strontium-90 was established. Utilizing low-level counting technics and routine chemistry, it was possible to measure physically significant levels of both isotopes. Valuable biological data were obtained as base line information for the spring 1956 tests at Eniwetok, and in addition, certain worthwhile biological implications became apparent. A heretofore unmeasured, acute inhalation strontium problem is discussed. Through the use of methods employed in the project, relatively reliable hazard predictions for acute exposure to iodine and strontium in man might be derived. In order to derive actual hazard values, however, additional specific information on strontium-90 kinetics in man is imperative.

The data indicated a possible direct relationship between iodine and strontium activities in the urine. If this is verified and the ratio delineated at a future test, it might be possible to estimate the acute strontium hazard by the measurement of urinary iodine alone.

In addition to the above, three questions were raised that require further consideration:

(1) The relative contributions of the acute (inhalation) and chronic (ingestion) exposure to the total biological hazard.

(2) The relationship of physical fallout and biological data.

(3) An evaluation of the contribution to the total biological hazard of other long half-life fission products.

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Acknowledgment

This report would not have been possible without the wholehearted cooperation of many individuals. Colonel R. P. Mason, MC, Chief of Research and Development Division, Army Surgeon General's Office, and Lt. Colonel S. E. Lifton, MC, Air Surgeon General's Office, arranged for the collection of specimens. The Commanding Officers of the Medical Units and the men involved were particularly conscientious.

Lt. Colonel J. T. Brennan, MC, WRAH, contributed valuable advice and encouragement throughout the project.

Colonel Roy D. Maxwell, MSC, Armed Forces Special Weapons Project, aided the inception of the project and contributed technical advice for the chemical procedures.

Mr. Merrill Eisenbud and Dr. John Harley, New York Operations Office, Atomic Energy Commission, provided the physical fallout data. Dr. A. Machta and Mr. R. List, United States Weather Bureau, provided the cloud trajectory data.

Dr. Gustave Klinck, Armed Forces Institute of Pathology, arranged for the human thyroid gland analysis.

Drs. Howard Andrews, National Institutes of Health, and A. K. Solomon, Harvard Medical School, kindly reviewed portions of the report.

Valuable technical assistance during the project was made by Cpl. John Landgraf, Pvt. William D. Cash, Pvt. James F. Keegan, Pvt. Robert Troiano and Pvt. Royal Merritt.

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Letterman Army Hospital, San Fransisco, California "A"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample															
1	Vol.	1200	1400	1400	2000	1150	-	-	1200	1200	-	1250	900	800	1100
	dpm	25.5	11.0	5.4	15.4	27.4	-	-	-	4.7	9.8	15.4	13.2	25.8	11.7
6	Vol.	2300	2200	1250	2250	800	1250	2000	1800	1200	-	2000	-	-	-
	dpm	0.0	17.0	0.0	26.8	26.1	1.6	11.3	5.0	2.5	9.8	3.2	-	-	-
10	Vol.	1150	1500	1500	1700	1700	1600	2000	1700	2100	-	1200	1800	1250	1250
	dpm	23.3	7.2	9.1	5.4	0.0	22.1	3.8	1.6	4.1	15.4	5.7	7.2	13.9	40.6
11	Vol.	1000	400	750	1000	1200	1100	800	750	500	-	1200	1100	1000	750
	Creatinine		0.5							0.9					
	dpm	8.5	26.1	4.1	20.8	11.0	0.0	5.0	6.9	3.8	6.9	15.4	17.0	0.0	33.7
13	Vol.	950	1000	850	1000	1200	-	800	1100	850	-	1200	1000	1000	-
	dpm	34.0	3.15	8.2	15.4	9.1	1.2	8.5	5.0	9.5	2.8	7.9	0.0	13.9	-
14	Vol.	2250	1700	1900	1700	1650	1300	1400	1250	1800	-	1300	1300	2000	750
	dpm	12.6	17.6	0.0	14.5	9.5	18.6	0.0	0.0	0.0	3.5	6.9	0.9	2.5	15.8
16	Vol.	1350	1300	900	1350	1200	1050	1100	1000	1300	-	1000	1000	1000	1250
	dpm	22.7	17.6	2.8	11.0	5.3	20.2	11.3	0.0	9.5	5.7	13.9	1.9	0.0	23.3
17	Vol.	1150	2400	1600	1800	1800	1800	1800	1700	1800	-	1200	2000	2000	1750
	dpm	16.7	7.6	19.5	5.7	33.4	15.7	29.6	6.3	0.0	7.6	12.6	2.5	17.3	15.8
18	Vol.	1050	800	1000	1000	900	1050	950	1250	750	-	1750	900	1100	1250
	dpm	13.5	27.1	12.0	12.0	13.9	6.5	16.7	0.0	7.5	1.6	3.8	17.0	13.2	48.8
19	Vol.	1800	1050	1300	1300	1750	1250	-	1500	1900	-	1700	1250	1050	2250
	dpm	26.8	11.7	37.8	1.6	15.1	4.4	-	6.9	0.0	6.3	2.5	9.8	0.0	35.6
22	Vol.	1150	1700	1300	1600	1300	1300	1000	1300	1300	-	1000	1300	1750	1000
	dpm	11.0	4.4	9.8	12.3	6.6	0.0	22.1	19.5	2.5	-	10.1	17.6	12.6	23.9

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Fitzsimons Army Hospital, Denver, Colorado

"B"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample															
1	Vol.	1000	1000	750	800	1150	800	1200	-	1300	500	1200	1100	-	-
	Creatinine										0.8				
	dpm	6.6	4.1	102.	161.	0.0	11.3	23.6	-	98.0	198.	83.9	-	-	-
2	Vol.	1750	1500	-	750	1200	1500	1300	-	1300	1500	-	-	-	-
	dpm	5.7	11.7	146	53.6	30.2	39.7	16.1	-	59.8	114.	-	-	-	-
3	Vol.	1100	1000	1700	1050	600	900	800	-	1000	750	1000	1700	1500	750
	Creatinine					1.0									
	dpm	19.2	6.9	37.5	38.4	12.3	7.2	0.0	-	57.6	26.8	10.1	-	116.	90.1
5	Vol.	2000	2200	1550	2000	2000	1300	1000	-	1000	-	-	-	-	-
	dpm	10.1	3.5	141.	110.	56.4	9.5	13.2	-	-	-	-	-	-	-
6	Vol.	1700	1450	1000	1200	1000	1500	1500	-	1000	1000	-	-	-	-
	dpm	14.8	10.4	268.	135.	88.5	31.2	10.4	-	87.9	473.	-	-	-	-
7	Vol.	750	1200	1100	1100	1200	1500	1400	-	600	1000	-	-	-	-
	Creatinine									0.6					
	dpm	14.8	20.2	84.1	36.5	20.8	5.7	2.8	-	14.8	186.	-	-	-	-
8	Vol.	1450	1600	1700	1750	1500	1600	2250	-	1500	1250	2000	1500	2000	1500
	dpm	4.1	12.0	114.	40.6	23.0	4.4	13.9	-	46.6	284.	35.9	-	114.	52.9
9	Vol.	850	900	2000	1000	750	800	1400	-	-	-	1400	1300	1500	1000
	dpm	0.0	6.3	256	97.3	31.2	12.0	16.1	-	-	-	98.9	-	80.0	398.
10	Vol.	650	750	-	750	1200	900	600	-	800	500	750	500	750	750
	Creatinine	1.2						1.1			1.0		1.0		
	dpm	6.6	9.8	-	60.2	40.0	13.5	10.4	-	48.2	254.	42.8	-	147.	132.
11	Vol.	1600	850	1200	1100	1000	1000	1250	-	1000	750	1200	1000	900	1250
	dpm	0.0	19.5	129.	34.7	31.5	41.3	1.3	-	63.9	233.	28.4	-	146.	125.
12	Vol.	1000	1250	1500	1750	900	900	1000	-	1000	1000	1100	750	250	750
	Creatinine													0.3	
	dpm	7.6	9.8	34.3	50.7	46.6	9.8	8.2	-	69.9	86.0	41.9	-	63.3	112.

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Brooke Army Hospital, San Antonio, Texas

"C"

Sample		Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
2	Vol.	-	-	-	-	1200	-	-	-	-	-	-	-	-	-
	dpm	-	-	-	-	5.7	-	-	-	-	-	-	5.7	-	-
3	Vol.	500	1550	900	700	-	1250	800	800	600	600	900	500	750	750
	Creatinine	0.9			0.8					0.6	0.9		0.7		
	dpm	21.1	11.7	4.1	7.2	-	18.0	6.3	7.9	0.6	0.0	0.0	3.5	3.5	9.8
8	Vol.	500	450	-	500	950	-	-	-	-	-	-	750	600	750
	Creatinine	0.8	0.6	-	0.4									1.0	
	dpm	3.2	0.0	-	12.6	27.4	-	-	-	-	-	-	13.9	42.5	73.4
10	Vol.	750	750	-	350	1200	750	500	500	750	800	750	-	500	2800
	Creatinine				0.6									0.7	
	dpm	10.1	33.4	-	13.2	29.3	20.8	4.1	20.8	15.4	21.4	17.3	-	9.8	18.0
11	Vol.	1500	2150	2250	1800	-	1500	3250	3250	2000	2100	2100	2100	2100	-
	dpm	12.0	-	11.7	17.6	-	28.0	6.3	31.5	12.3	6.3	0.0	6.9	5.7	-
12	Vol.	1500	1000	2000	-	1600	1100	1100	1100	1000	1000	1400	1250	1250	900
	dpm	7.6	10.1	0.0	-	19.2	20.8	2.2	0.0	6.9	0.0	22.1	-	57.6	19.5
13	Vol.	-	1200	1500	1250	1500	1150	1000	1000	1250	1200	-	1500	750	1250
	dpm	-	7.9	9.1	10.7	41.2	11.0	-	6.6	13.2	0.0	-	18.9	15.4	18.9
14	Vol.	1500	1500	850	-	2450	2100	-	-	-	-	-	-	-	-
	dpm	27.1	19.8	8.2	-	20.8	6.9	23.3	-	24.3	15.1	6.9	0.0	-	-
15	Vol.	1600	1000	1200	750	800	-	500	500	1750	1200	1750	-	1000	-
	Creatinine								0.8						
	dpm	5.4	9.8	9.1	11.0	18.6	-	7.9	4.1	7.9	11.0	7.6	-	13.9	-
17	Vol.	-	1400	-	1300	1000	1300	1600	1600	1000	1250	1250	1250	1250	-
	dpm	-	57.3	-	21.4	37.2	41.9	44.4	45.7	30.2	14.5	11.7	6.9	37.5	-
21	Vol.	1000	-	700	900	600	1000	-	-	-	-	-	-	-	-
	Creatinine		-			0.9									
	dpm	2.5	-	8.8	16.7	11.0	47.3	43.8	-	-	-	-	-	-	-

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"D"

Walter Reed Army Hospital, Washington, D.C.

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample															
1	Vol.	700	1000	400	700	1050	1200	750	-	950	1000	900	1000	1000	850
	Creatinine	1.1		0.5	1.0										
	dpm	0.0	3.2	0.3	38.4	10.1	11.0	21.4	-	22.3	-	30.6	5.7	35.0	33.7
2	Vol.	1700'	1300	800	1750	1500	800	2500	-	1000	1500	1000	1750	1250	-
	dpm	2.8	7.6	15.8	58.3	14.2	8.8	10.1	-	12.3	36.5	24.2	22.1	46.0	-
3	Vol.	1150	1250	1550	750	2100	2000	1250	1500	2500	2000	1250	1750	1150	1200
	dpm	6.6	7.6	0.0	6.6	12.6	6.0	-	6.0	10.4	69.9	26.4	6.9	32.1	34.3
4	Vol.	1000	1400	1100	1250	1950	1500	1200	750	1750	1200	500	1000	750	800
	Creatinine											0.8			
	dpm	3.8	7.2	0.0	6.0	8.2	23.0	13.5	8.5	10.4	53.2	14.2	12.6	13.2	97.6
5	Vol.	900	750	—	850	1250	1100	1100	1200	750	1000	600	700	750	1000
	Creatinine											1.0	1.0		
	dpm	7.9	23.0	17.3	4.1	6.3	15.4	27.4	15.4	6.0	19.5	13.2	7.2	17.0	45.7
6	Vol.	650	750	800	650	750	750	850	750	500	750	500	700	900	750
	Creatinine	1.1			1.1					0.9		0.9	1.1		
	dpm	11.0	78.8	2.5	8.2	33.1	19.2	20.5	9.5	7.2	48.5	22.4	45.4	41.9	33.4
7	Vol.	1450	1750	1000	1200	1750	1500	1000	1250	1600	1000	2000	2000	2000	1900
	dpm	8.5	3.8	13.2	5.7	17.3	152.	31.2	7.9	14.2	22.1	31.8	23.6	56.1	81.6
8	Vol.	1400	1250	1750	1650	750	1000	1000	1750	1250	2000	-	1700	-	800
	dpm	0.3	12.3	11.7	2.5	14.2	6.3	12.3	4.7	12.6	55.1	-	21.7	-	15.1
9	Vol.	1050	1500	750	1300	500	750	750	750	750	750	750	1500	900	800
	Creatinine					0.8									
	dpm	0.0	36.3	7.2	9.5	11.3	21.7	19.2	3.8	7.2	48.2	42.8	16.7	38.7	36.5
10	Vol.	1600	-	1500	1150	1200	1500	1250	1200	1700	1700	1500	1000	1000	1000
	dpm	5.4	-	7.9	10.7	25.2	7.2	11.0	4.4	16.7	32.1	36.5	11.0	21.1	66.2
11	Vol.	750	750	1400	1000	800	900	900	750	1200	1000	600	1300	1100	750
	Creatinine											0.9			
	dpm	8.5'	14.7	4.4	11.0	7.2	-	1.3	3.5	11.7	49.1	39.7	18.0	24.3	52.0
12	Vol.	950	900	1500	1100	1900	1600	1350	1600	1000	1500	750	-	1500	1250
	dpm	0.0	9.4	12.6	10.7	3.8	8.2	18.9	8.5	5.4	15.8	-	-	23.3	40.3

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Fairchild Air Force Base, Spokane, Washington "E"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample															
1	Vol.	1100	800	1000	750	1100	800	1000	900	-	-	-	-	-	-
	dpm	51.3	10.4	4.7	28.4	25.8	7.9	0.0	0.0	-	-	-	-	-	-
2	Vol.	1550	2000	1200	1500	1650	1200	1250	1500	-	-	-	-	-	-
	dpm	38.1	10.4	17.0	20.8	8.5	2.5	3.9	6.3	-	-	-	-	-	-
3	Vol.	900	1100	1000	750	900	1000	800	-	-	-	-	-	-	-
	dpm	24.3	10.4	0.0	22.1	35.9	0.0	0.6	-	-	-	-	-	-	-
4	Vol.	500	-	-	-	-	1000	600	-	-	-	-	-	-	-
	Creatinine	0.8						0.9							
	dpm	17.3	-	-	-	-	2.5	4.4	-	-					
5	Vol.	-	1400	-	1700	1250	1750	-	-	-	-	-	-	-	-
	dpm	-	9.8	-	24.9	18.6	6.9	-	-	-	-	-	-	-	-
6	Vol.	250	450	500	600	450	600	500	450	-					
	Creatinine	0.4	0.6	0.7	0.7	0.6	1.0	0.8	0.4	-	-	-	-	-	-
	dpm	49.1	14.5	8.5	15.1	28.0	18.0	0.0	0.0	-					
7	Vol.	-	1000	800	-	-	-	-	-	-	-	-	-	-	-
	dpm	-	15.4	0.0	-	-	0.0	-	-	-	-	-	-	-	-
8	Vol.	1000	1000	1000	750	1100	750	600	750	-	-	-	-	-	-
	dpm	20.8	13.9	4.1	11.0	18.6	-	3.8	0.0	-	-	-	-	-	-
9	Vol.	1750	1300	1550	1800	1250	1300	1100	1850	-	-	-	-	-	-
	dpm	11.7	24.9	-	1.9	17.3	2.7	0.0	9.4	-	-	-	-	-	-
10	Vol.	500	750	-	500	-	250	-	600						
	Creatinine	0.8			0.8		0.4		0.8	-	-	-	-	-	-
	dpm	11.0	52.9	13.9	13.9	-	15.8	-	0.9						
11	Vol.	1700	750	200	900	1150	500	1000	1500	-	-	-	-	-	-
	Creatinine			0.3			0.7								
	dpm	5.7	8.5	0.9	16.1	22.7	3.8	3.8	0.0	-	-	-	-	-	-

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March Air Force Base, Riverside, California "H"

Sample		Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
1	Vol.	900	750	700	800	1000	1500	1500	1250	1250	1250	1200	1100	1000	750
	dpm	18.3	37.8	0.9	14.8	41.9	11.3	5.4	7.0	10.1	0.0	1.3	24.6	22.9	45.7
2	Vol.	750	1100	850	1800	500	1000	900	1000	1500	1200	-	-	-	-
	Creatinine					0.6									
	dpm	14.8	39.7	16.4	17.0	14.8	10.4	2.5	5.7	2.2	0.0	-	-	-	-
3	Vol.	900	850	1200	1750	2050	1750	1500	750	1150	2000	900	800	750	2800
	dpm	21.7	39.1	18.9	12.3	21.7	4.1	0.0	1.6	0.0	0.0	18.9	11.0	5.0	28.4
4	Vol.	1000	1300	2200	1850	1150	1500	1800	1000	750	1250	1000	900	-	-
	dpm	16.4	18.3	34.0	14.8	4.7	0.0	4.7	3.5	5.0	0.0	0.0	0.0	-	-
5	Vol.	1500	1200	1175	750	1250	900	900	900	1000	-	-	-	-	-
	dpm	15.1	30.6	25.8	20.8	12.3	2.7	6.3	0.0	8.5	-	-	-	-	-
6	Vol.	750	700	400	1000	500	1000	800	850	1000	800	800	600	750	1500
	Creatinine		1.2	0.6		0.9							1.1		
	dpm	1.3	10.7	42.8	39.7	17.0	-	0.0	0.0	2.8	13.9	1.3	8.2	24.3	69.6
7	Vol.	1400	750	800	900	1000	1000	1000	1500	1000	1250	800	1100	1000	800
	dpm	2.2	40.6	43.5	29.9	27.1	5.4	5.7	0.0	6.9	3.8	8.2	15.4	19.5	32.1
8	Vol.	-	-	-	1800	-	-	-	-	-	-	-	-	-	-
	dpm	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Vol.	1400	400	1425	-	1900	1850	1400	1250	750	800	1500	1000	1500	1800
	Creatinine		0.6												
	dpm	10.1	12.6	0.0	22.0	10.1	9.8	5.4	4.7	5.7	3.8	7.6	20.8	12.6	27.7
10	Vol.	1000	800	1500	750	750	1600	950	2250	2250	2100	1300	1300	1250	1250
	dpm	7.6	37.2	16.7	13.9	4.7	0.9	2.2	8.5	6.3	12.0	5.7	6.9	5.0	49.5
11	Vol.	1000	750	1100	1000	650	800	1000	600	750	1200	-	-	-	-
	Creatinine					1.2			1.1						
	dpm	11.0	35.9	13.9	16.7	0.0	2.8	1.6	4.1	0.0	3.2	-	-	-	-

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March Air Force Base, Riverside, California (Cont'd)

"H"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample															
12	Vol.	-	-	-	-	-	-	-	-	-	-	1200	1600	1700	1250
	dpm	-	-	-	-	-	-	-	-	-	0.6	1.9	5.4	18.6	71.8
13	Vol.	-	-	-	-	-	-	-	-	-	-	1250	2100	1400	2000
	dpm	-	-	-	-	-	-	-	-	-	-	7.6	4.1	17.0	15.8
14	Vol.	-	-	-	-	-	-	-	-	-	-	-	1200	1100	1200
	dpm	-	-	-	-	-	-	-	-	-	-	-	7.9	12.6	31.5
15	Vol.	-	-	-	-	-	-	-	-	-	-	-	-	1750	2500
	dpm	-	-	-	-	-	-	-	-	-	-	-	-	5.7	19.5

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Luke Air Force Base, Phoenix, Arizona "K"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample															
1	Vol.	1100	2300	2000	2400	1900	2000	2200	1750	900	2200	1300	-	2300	1500
	dpm	7.6	36.5	18.0	6.9	20.8	66.1	66.8	0.0	36.9	22.1	17.0	-	45.4	34.0
2	Vol.	1550	650	1250	1100	1500	950	1100	1450	1100	1000	1200	-	-	-
	Creatinine		1.2												
	dpm	8.1	11.3	15.1	11.0	5.0	12.6	117.	0.0	18.6	32.4	27.7	-	-	-
3	Vol.	2800	2800	2800	2800	2800	2800	2800	2800	2800	2800	2800	2800	2800	2800
	dpm	22.7	36.5	20.5	51.0	8.2	1.6	16.4	0.0	17.3	25.5	7.6	4.1	25.2	32.8
4	Vol.	1000	1250	800	1050	500	1000	1000	1250	1500	1200	1500	1000	850	1250
	Creatinine					0.7									
	dpm	21.8	26.5	12.3	39.1	0.0	44.4	12.9	48.8	22.1	6.9	26.5	6.9	79.1	34.0
5	Vol.	850	1050	1200	550	1100	1000	1000	750	1250	1250	1700	800	750	750
	Creatinine				0.9										
	dpm	8.8	28.4	9.8	38.1	69.3	42.2	61.1	0.0	46.3	16.1	25.8	24.3	27.4	94.[illegible]
6	Vol.	1000	1600	1100	800	1000	650	1750	1500	750	1750	900	1000	900	1000
	Creatinine						1.0								
	dpm	8.8	31.5	11.7	57.0	13.9	15.1	34.3	141.	23.0	25.5	32.1	17.3	39.1	22.[illegible]
7	Vol.	750	1250	1100	1400	750	250	750	1500	1000	500	1100	800	800	750
	Creatinine						0.4				0.7				
	dpm	8.2	38.4	16.4	62.4	0.0	41.0	19.8	96.7	45.0	24.3	3.8	0.0	35.9	61.
8	Vol.	1800	1500	1200	950	1250	1000	1400	1000	500	750	1700	1500	850	105[illegible]
	Creatinine									0.6					
	dpm	24.6	36.5	7.6	8.2	29.3	118.	226.	324.	38.1	3.7	46.6	4.7	24.3	116
9	Vol.	750	950	500	800	600	500	250	-	-	-	-	-	-	-
	Creatinine			0.7		0.5	0.6	0.4							
	dpm	24.3	31.5	11.0	21.7	11.7	92.9	19.2	-	-	-	-	-	-	-

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Luke Air Force Base, Phoenix, Arizona (Cont'd)

"K"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample 10	Vol.	1500	1450	1600	850	1200	800	1000	1250	2000	-	1400	-	-	-
	dpm	18.6	32.1	12.3	7.6	3.5	38.7	58.0	196.	50.7	12.6	29.0	-	-	-
11	Vol.	-	-	-	-	-	-	-	1000	1750	1200	1750	1200	-	1000
	dpm	-	-	-	-	-	-	-	-	-	-	4.4	-	-	95.8
12	Vol.	-	-	-	-	-	-	-	-	-	-	-	1250	1000	750
	dpm	-	-	-	-	-	-	-	-	-	-	-	4.7	49.5	49.1
13	Vol.	-	-	-	-	-	-	-	-	-	-	-	-	-	800
	dpm	-	-	-	-	-	-	-	-	-	-	-	-	-	42.8

[redacted]

[redacted]

Lockbourne Air Force Base, Columbus, Ohio "L"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample 1	Vol.	500	750	750	1100	900	1200	600	1000	750	750	1500	1000	-	750
	Creatinine	0.5						0.7							
	dpm	24.3	4.1	14.8	16.1	7.8	18.5	7.6	11.0	2.8	8.5	10.1	11.7	-	9.1
2	Vol.	750	700	700	700	750	750	750	800	700	1300	600	1200	1000	1250
	Creatinine		1.1	0.9	1.0					1.0		0.9			
	dpm	18.9	15.1	5.7	33.1	8.2	9.5	6.3	5.7	17.3	3.5	8.2	16.1	2.8	61.4
3	Vol.	1500	1750	1100	1150	1600	1000	1000	1250	1500	1200	1300	-	1250	1500
	dpm	37.2	0.0	15.4	16.7	14.5	11.0	1.6	3.2	6.3	24.9	25.2	-	40.3	86.9
4	Vol.	700	700	1000	800	650	750	750	500	-	1100	750	-	-	-
	Creatinine	1.2	1.1			1.0			0.9						
	dpm	26.8	27.9	2.8	9.8	15.1	3.2	9.5	4.1	-	46.0	33.1	-	-	-
5	Vol.	-	-	-	900	1200	1000	800	300	750	750	750	500	500	750
	Creatinine								0.5				1.0	0.8	
	dpm	-	-	-	11.0	14.5	15.4	9.5	0.9	4.1	25.8	1.6	22.1	47.2	58.6
6	Vol.	1000	900	1500	1000	1200	1000	600	600	-	-	-	-	-	750
	Creatinine							1.1	0.8						
	dpm	27.4	23.0	11.0	15.1	30.2	29.0	3.1	1.3	-	-	-	-	-	47.9
7	Vol.	1300	750	1750	900	1100	1000	1000	1200	1000	550	800	-	1200	1500
	Creatinine										1.0				
	dpm	2.2	18.6	5.7	12.3	8.2	5.4	8.5	3.5	11.0	57.0	30.9	-	59.2	70.6
8	Vol.	1050	700	700	-	-	-	-	-	1000	750	-	500	500	850
	Creatinine		1.2	1.1									0.8	0.6	
	dpm	18.0	17.3	6.9	-	-	-	-	-	5.7	6.3	-	29.0	32.8	63.0
9	Vol.	1250	1250	1200	900	2000	1100	600	800	750	750	1000	1000	1000	1250
	Creatinine							1.0							
	dpm	11.0	11.0	4.4	14.5	26.1	11.0	13.9	13.2	18.0	45.7	19.5	24.3	18.3	21.1
10	Vol.	500	1100	800	1000	350	-	750	1000	750	750	900	700	600	750
	Creatinine	0.7				0.5							1.0	1.0	
	dpm	9.1	12.9	4.1	12.6	9.1	-	9.1	0.0	14.5	34.7	29.3	20.2	22.7	65.2

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Tinker Air Force Base, Oklahoma City, Oklahoma

[redacted]

"M"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample 1	Vol.	1500	750	1200	1450	750	250	250	1950	1250	700	200	-	750	750
	Creatinine						0.5				0.8	0.3			
	dpm	195.0	28.4	8.5	18.6	67.7	0.0	8.5	29.0	15.1	0.0	1.9	-	13.9	32.1
2	Vol.	1500	1700	2800	1400	1200	2250	1750	1500	2500	2400	1750	1250	1700	1450
	dpm	10.1	29.6	14.8	27.1	38.1	32.8	24.2	35.2	11.7	3.8	47.9	56.1	216.	23.3
3	Vol.	900	900	950	1550	1100	1650	1200	1100	1500	1000	850	900	-	-
	dpm	1.3	8.8	21.1	27.1	60.8	23.0	8.5	20.8	6.3	2.8	1.9	9.8	-	-
4	Vol.	1900	1000	1325	1100	1950	2500	1250	1600	1250	2000	-	-	1500	-
	dpm	17.3	14.5	32.8	11.7	67.1	17.3	34.0	41.6	12.0	10.7	-	-	105.	-
5	Vol.	1500	950	1100	1600	1200	1150	600	1200	1250	2500	1200	1750	1200	1250
	dpm	22.7	-	21.7	29.0	89.5	11.0	18.6	42.8	30.6	11.7	5.7	31.2	208.	473.
6	Vol.	1750	600	1850	1950	2450	700	750	1000	1000	750	-	-	-	-
	Creatinine		0.5				1.1								
	dpm	12.9	5.0	25.8	18.0	53.5	16.1	10.7	14.2	40.3	0.0	-	-	-	-
7	Vol.	1800	750	1375	1000	950	1000	900	1000	250	-	900	500	1300	1250
	Creatinine									0.4			0.6		
	dpm	17.4	10.1	9.1	22.4	25.8	36.6	29.3	18.9	10.4	8.5	10.7	7.6	81.0	297.
8	Vol.	1000	1000	1200	1100	1250	900	1500	-	-	-	400	1000	750	1250
	Creatinine											0?7			
	dpm	23.6	35.9	8.5	16.4	85.1	16.7	23.0	-	-	-	5.7	43.2	174.	567.
9	Vol.	900	1000	1100	1100	1500	1100	1000	900	1750	750	1200	-	-	-
	dpm	19.8	-	15.1	31.2	78.4	8.5	32.8	45.4	25.8	-	13.2	-	-	-
10	Vol.	800	800	-	-	-	950	-	-	-	-	-	-	-	-
	dpm	35.9	-	-	-	-	18.9	28.4	-	-	-	-	-	-	-
11	Vol.	-	-	-	-	-	-	700	800	900	1250	500	500	800	900
	Creatinine											0.8	0.7		
	dpm	-	-	-	-	-	-	-	37.5	49.1	8.5	13.9	35.9	92.6	347.

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Hill Air Force Base, Ogden, Utah

"N"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22	1	8	15	22	29	5	12	19	26	3	10	17	24
Sample		Feb.	Mar.	Mar.	Mar.	Mar.	Mar.	Apr.	Apr.	Apr.	Apr.	May	May	May	May
1	Vol.	1600	1750	2150	2000	1500	2500	2000	1850	2500	2500	-	-	-	-
	dpm	31.3	5.4	35.9	74.0	27.4	19.5	36.5	51.7	434.	236.	-	-	-	-
2	Vol.	1250	1500	1500	1700	1550	1700	1600	1100	-	1250	-	-	-	-
	dpm	0.0	13.2	23.9	67.7	23.9	18.9	17.6	50.7	-	246.	-	-	-	-
3	Vol.	800	1200	1500	1850	1900	1000	1200	1250	1600	2000	-	-	-	-
	dpm	39.4	14.5	51.3	66.2	18.9	16.7	20.8	39.4	348.	235.	-	-	-	-
4	Vol.	1300	1550	1900	1900	1500	1800	1600	1750	1850	2000	-	-	-	-
	dpm	25.4	11.0	39.1	54.5	30.2	19.2	16.1	42.5	222.	222.	-	-	-	-
5	Vol.	1300	1100	1100	750	1650	1500	750	1200	1250	2250	-	-	-	-
	dpm	15.6	16.4	47.6	37.2	18.6	31.8	21.7	52.9	483.	287.	-	-	-	-
6	Vol.	2650	1400	2000	1500	2800	1500	1000	2600	2200	2100	-	-	-	-
	dpm	16.4	3.2	24.3	99.5	39.1	20.5	18.0	68.7	467.	312.	-	-	-	-
7	Vol.	1000	1000	1400	1250	1000	1200	750	1000	1100	1250	-	-	-	-
	dpm	20.2	1.3	42.2	34.0	20.8	15.4	15.1	51.7	494.	358.	-	-	-	-
8	Vol.	1450	1500	1750	1300	1700	1300	1500	1750	1550	1950	-	-	-	750
	dpm	11.7	12.3	28.7	60.5	40.6	13.2	19.5	44.1	618.	495.	-	-	-	530.
9	Vol.	1000	750	1750	700	550	1250	-	-	-	-	-	-	-	750
	Creatinine					1.0						-	-	-	-
	dpm	27.8	0.0	24.9	37.2	13.2	16.7	-	-	-	-	-	-	-	498.
10	Vol.	1200	900	1250	1150	1750	1000	750	1500	1000	1500	-	-	-	-
	dpm	29.3	12.0	40.6	56.7	10.7	14.8	23.3	33.7	315.	153.	-	-	-	-

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Scott Air Force Base, Belleville, Illinois

"0"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
Sample															
1	Vol.	1000	1000	1250	-	1250	800	1000	900	1750	1300	-	-	-	900
	dpm	0.0	22.4	31.2	124.	152.	23.3	33.4	258.	18.9	143.	-	-	243.	98.6
2	Vol.	-	1000	1000	-	1500	750	-	-	-	-	-	-	1750	-
	dpm	-	50.1	32.8	74.7	128.	14.8	-	-	-	-	-	-	170.	-
3	Vol.	750	750	1200	-	1150	1100	750	1000	1200	1000	-	-	1100	1100
	dpm	0.0	31.2	12.0	69.9	146.	22.4	26.5	42.8	181.	133.	-	-	175	92.9
4	Vol.	1000	1250	750	-	1250	1300	1000	1250	1000	1500	-	-	1000	1000
	dpm	0.0	24.9	32.1	31.2	137.	178.	45.4	49.8	170.	63.0	-	-	313.	151.
5	Vol.	1350	1300	1100	-	1700	1350	1600	2300	1000	1450	-	-	1000	1000
	dpm	0.0	22.4	13.2	129.	90.1	62.7	44.7	39.1	85.1	104.	-	-	-	-
6	Vol.	500	600	700	-	-	500	750	1500	1200	750	-	-	800	800
	Creatinine	0.5	0.8	0.8			0.7								
	dpm	4.1	24.3	43.2	12.3	-	41.0	9.5	31.5	69.3	57.0	-	-	69.3	38.7
7	Vol.	1500	1350	800	-	1200	1500	1750	400	400	-	-	-	750	1250
	Creatinine								0.7	0.6					
	dpm	0.0	27.7	10.4	28.0	83.2	52.9	32.1	33.1	331.	-	-	-	105.	42.5
8	Vol.	2500	2500	1800	-	1750	1250	1200	800	1000	2750	-	-	-	1500
	dpm	0.0	31.5	36.2	43.8	113.	54.2	30.2	55.8	52.9	159.	-	-	-	376.
9	Vol.	1500	1250	600	-	1000	750	750	750	700	750	-	-	1000	900
	Creatinine			1.0						1.0					
	dpm	1.6	51.7	16.7	55.1	108.	52.6	22.7	18.6	222.	85.7	-	-	106.	73.4
12	Vol.	750	1150	1500	-	1800	1750	1600	1750	750	1300	-	-	800	750
	dpm	0.0	24.6	47.6	10.1	43.5	34.0	33.1	11.0	51.0	30.9	-	-	35.9	76.5
13	Vol.	600	2000	750	-	2000	1850	1750	1750	2000	1300	-	-	1000	1800
	Creatinine	1.1													
	dpm	0.0	55.4	6.9	161.	205.	47.3	87.9	79.7	-	290.	-	-	136.	70.6

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Selfridge Air Force Base, Mt. Clemens, Michigan "P"

Sample	Week / Date	1 22 Feb.	2 1 Mar.	3 8 Mar.	4 15 Mar.	5 22 Mar.	6 29 Mar.	7 5 Apr.	8 12 Apr.	9 19 Apr.	10 26 Apr.	11 3 May	12 10 May	13 17 May	14 24 May
1	Vol.	500	1250	1000	1500	1100	1750	750	1750	-	-	750	1750	1000	1000
	Creatinine	0.4													
	dpm	48.8	Comb	38.4	35.9	39.7	8.8	0.0	2.3	-	-	27.1	29.0	45.0	35.0
2	Vol.	400	750	550	1300	1500	1250	1000	1800	1500	1300	700	750	750	1250
	Creatinine	0.6		0.9								1.1			
	dpm	96.1	Comb	33.7	9.8	12.0	30.2	14.5	4.1	21.4	53.6	25.5	47.9	62.7	29.0
3	Vol.	1250	1500	2200	850	1250	1550	1300	-	750	300	-	1400	1500	1750
	Creatinine										0.5				
	dpm	57.6	Comb	23.9	23.6	38.7	-	5.7	-	13.9	8.8	-	27.1	30.6	41.6
4	Vol.	1200	500	1750	750	500	600	1000	1000	500	250	750	600	750	750
	Creatinine		0.9			0.7	0.7			0.7	0.4				
	dpm	63.0	Comb	23.9	5.0	6.3	14.5	10.7	26.1	2.5	13.2	56.4	7.6	36.9	39.7
5	Vol.	350	700	750	750	500	500	750	500	750	500	-	1200	500	-
	Creatinine	0.7	1.2			1.0	0.5		0.9	0.7	0.3			0.8	
	dpm	63.0	Comb	29.6	5.7	15.4	0.6	5.7	67.4	8.8	0.0	-	28.0	8.5	-
6	Vol.	900	500	750	2500	1200	1900	1000	2250	1000	750	800	1250	-	750
	Creatinine		0.7												
	dpm	35.6	Comb	52.3	-	17.3	22.1	6.9	18.6	7.6	47.3	22.1	49.5	-	86.0
7	Vol.	-	500	2650	400	2300	550	1750	2500	2500	2400	1000	1800	1500	1000
	Creatinine		0.5		0.5		0.5								
	dpm	-	Comb	23.3	13.2	19.5	3.5	5.0	-	17.0	11.0	25.5	4.7	28.4	58.9
8	Vol.	550	1500	1550	400	1250	1240	-	1250	750	750	600	1650	300	750
	Creatinine	0.9			0.5							1.1			
	dpm	36.5	Comb	18.6	9.8	8.5	15.1	-	7.6	9.5	8.2	28.7	79.1	56.4	35.0
9	Vol.	1000	700	850	750	1200	1300	-	750	1500	-	1200	1500	1500	1700
	Creatinine		1.0												
	dpm	37.8	Comb	9.8	63.9	17.3	11.7	-	0.0	17.6	-	72.8	17.3	49.1	44.2
10	Vol.	1100	1000	400	1700	2000	1750	1000	700	400	1700	-	1200	-	1800
	Creatinine			0.7						0.6					
	dpm	19.2	Comb	13.9	13.9	15.1	18.0	8.8	2.8	5.0	22.7	-	8.8	-	25.2

Av. 1.4 [redacted]

Comb. - All samples combined for this week.

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Donaldson Air Force Base, Greenville, South Carolina "S"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date Sample		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
1	Vol.	850	1200	600	1750	1500	600	750	1100	1250	-	-	-	-	-
	Creatinine			0.8			1.0								
	dpm	49.8	12.0	6.9	13.9	4.7	2.2	13.9	11.3	7.6	-	-	-	-	-
2	Vol.	900	1000	1300	1250	1000	800	1500	1000	-	1000	-	-	-	-
	dpm	58.0	29.3	13.2	32.1	13.2	9.8	13.2	9.5	-	0.0	-	-	-	-
3	Vol.	1000	1000	900	1300	1000	1750	3500	1000	1250	1000	-	800	2500	-
	dpm	47.9	16.7	88.2	2.2	52.6	38.7	11.3	6.9	10.7	0.0	-	12.6	26.5	-
4	Vol.	1300	1250	1300	1250	1300	750	900	900	450	750	550	750	850	750
	Creatinine									0.6		0.7			
	dpm	19.5	7.6	6.3	8.8	12.0	8.2	5.0	0.0	22.0	0.0	0.0	4.1	36.9	29.3
5	Vol.	2000	750	750	2700	1000	2800	-	-	-	-	-	-	-	-
	dpm	39.7	11.7	5.0	10.4	0.6	4.1	-	-	-	-	-	-	-	-
6	Vol.	1250	700	1000	750	750	750	750	750	750	1000	-	-	1200	1100
	Creatinine		1.5												
	dpm	24.6	59.9	1.9	19.8	60.5	10.4	12.6	39.1	53.6	1.3	-	-	64.3	25.5
7	Vol.	750	250	400	2000	1200	800	-	-	-	1000	1500	-	-	900
	Creatinine		0.4	0.6											
	dpm	31.5	35.3	5.7	28.0	54.8	27.7	-	-	-	0.0	0.9	-	-	1.6
8	Vol.	1250	750	1250	800	1750	2600	-	-	-	-	-	-	-	-
	dpm	23.9	37.5	0.0	6.3	20.2	27.1	-	-	-	-	-	-	-	-
9	Vol.	2100	2800	2250	-	-	-	-	-	-	-	-	-	-	-
	dpm	24.6	13.9	3.2	-	-	-	-	-	-	-	-	-	-	-
10	Vol.	1500	750	1650	1600	1500	750	1000	-	500	1000	1250	600	-	-
	Creatinine									0.7			1.1		
	dpm	7.6	42.5	0.0	31.5	12.0	30.9	5.0	-	6.3	9.1	1.6	12.6	-	-
11	Vol.	-	-	-	1000	-	1000	1000	800	1100	1500	-	750	1000	-
	dpm	-	-	-	15.1	-	49.8	33.4	15.1	13.9	10.4	-	7.6	59.2	-

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Donaldson Air Force Base, Greenville, South Carolina (Cont'd) "S"

Sample		1 22 Feb.	2 1 Mar.	3 8 Mar.	4 15 Mar.	5 22 Mar.	6 29 Mar.	7 5 Apr.	8 12 Apr.	9 19 Apr.	10 26 Apr.	11 3 May	12 10 May	13 17 May	14 24 May
12	Vol.	-	-	-	-	2700	-	750	-	-	750	1000	2500	-	2900
	dpm	-	-	-	-	0.0	-	25.2	-	-	-	10.1	10.7	-	20.2
13	Vol.	-	-	-	-	-	-	1250	500	1300	-	1000	-	-	-
	Creatinine	-	-	-	-	-	-		0.7						
	dpm	-	-	-	-	-	-	3.8	4.4	23.9	15.8	8.5	-	-	-
14	Vol.	-	-	-	-	-	-	1000	1200	1100	1700	750	-	750	900
	dpm	-	-	-	-	-	-	24.6	15.8	36.5	17.3	9.5	-	42.2	16.4
15	Vol.	-	-	-	-	-	-	-	1100	600	-	-	600	800	950
	Creatinine	-	-	-	-	-	-			1.0			1.1		
	dpm	-	-	-	-	-	-	-	16.4	24.6	-	-	14.8	28.4	21.7
16	Vol.	-	-	-	-	-	-	-	500	450	950	1200	750	750	850
	Creatinine	-	-	-	-	-	-		0.8	0.6					
	dpm	-	-	-	-	-	-	-	17.6	17.0	-	18.0	15.1	48.5	30.9
17	Vol.	-	-	-	-	-	-	-	-	-	-	1300	700	750	900
	Creatinine	-	-	-	-	-	-						1.1		
	dpm	-	-	-	-	-	-	-	-	-	-	27.1	16.1	52.9	12.6
18	Vol.	-	-	-	-	-	-	-	-	-	-	1250	-	-	-
	dpm	-	-	-	-	-	-	-	-	-	-	17.3	-	-	-
19	Vol.	-	-	-	-	-	-	-	-	-	-	900	-	-	-
	dpm	-	-	-	-	-	-	-	-	-	-	21.1	-	-	-
20	Vol.	-	-	-	-	-	-	-	-	-	-	-	800	-	1000
	dpm	-	-	-	-	-	-	-	-	-	-	-	12.6	-	19.5
21	Vol.	-	-	-	-	-	-	-	-	-	-	-	1000	-	-
	dpm	-	-	-	-	-	-	-	-	-	-	-	16.7	-	-

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Mac Dill Air Force Base, Tampa, Florida "T"

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Date Sample		22 Feb.	1 Mar.	8 Mar.	15 Mar.	22 Mar.	29 Mar.	5 Apr.	12 Apr.	19 Apr.	26 Apr.	3 May	10 May	17 May	24 May
1	Vol.	-	1150	1500	800	1000	1800	1000	1200	1250	1600	1250	-	1900	1250
	dpm	-	4.1	22.1	61.7	1.6	31.5	24.6	5.7	11.0	22.4	9.5	-	41.6	12.6
2	Vol.	-	1250	1000	750	650	1000	800	1000	1250	-	1000	1000	1000	1000
	dpm	-	0.0	15.1	77.2	49.9	25.8	15.1	11.7	23.6	-	17.6	53.6	55.4	42.5
3	Vol.	-	1500	1000	2700	2100	1900	2250	2300	-	2250	1750	1250	1700	1200
	dpm	-	4.7	10.4	19.2	13.2	23.9	37.8	29.9	12.0	15.4	0.0	17.0	31.2	8.8
4	Vol.	-	1550	2300	1000	1800	1300	1000	-	900	1400	1100	1000	1300	900
	dpm	-	0.6	20.5	35.9	15.1	13.9	8.2	49.1	15.4	7.9	12.6	48.8	53.2	30.9
5	Vol.	-	1600	1400	2000	2000	1500	750	1400	900	1250	2000	1500	1450	-
	dpm	-	6.9	7.6	3.2	17.3	5.7	22.7	-	7.6	12.6	15.8	28.0	22.1	-
6	Vol.	-	1500	1200	1250	850	1550	1000	-	1250	1000	-	1500	1000	800
	dpm	-	2.2	31.5	25.2	29.0	57.0	34.0	-	8.2	10.7	-	22.1	55.4	41.6
7	Vol.	-	900	1400	750	850	1600	1350	1100	1000	1250	1000	900	1950	750
	dpm	-	6.9	22.7	18.0	16.7	32.1	98.3	3.5	-	15.4	24.6	33.1	48.5	28.0
8	Vol.	-	250	1600	-	500	1100	-	400	800	-	-	-	1200	-
	Creatinine		0.4			0.8			0.4						
	dpm		6.9	26.8	-	7.6	3.8	-	6.9	29.9	-	-	-	52.0	-
9	Vol.	-	1800	1150	1250	1750	1650	1750	1250	2000	1750	1500	1450	1800	1500
	dpm	-	19.2	23.3	3.2	42.5	23.9	15.8	47.9	5.7	9.8	23.3	22.1	76.2	47.3
10	Vol.	-	-	1250	1700	1000	-	1000	1800	750	2000	1750	1000	1700	900
	dpm	-	-	31.5	10.4	4.7	-	10.1	25.8	7.6	18.6	14.5	11.7	8.2	38.7
11	Vol.	-	-	1700	-	-	-	1100	1250	1750	1650	1000	1000	1700	750
	dpm	-	-	26.1	-	-	-	20.8	18.0	18.9	15.1	22.1	24.6	102.	47.2

[redacted]

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APPENDIX B-1

EXTRACTION AND COUNTING OF URINARY IODINE-131 (IODINE-133)

In order to process the 24-hour samples of urine in suitable time to get satisfactory counts for iodine, it was necessary to devise a simple extraction procedure which offered reasonable recovery of iodine and yet did not produce a specimen which would interfere significantly with counting beta radiation. Procedures in the literature did not meet these criteria, since they were not designed to handle large numbers of samples of considerable volume. The procedure reported herein offers promise in meeting the requirements. Refinements of the technic are being investigated at the writing of this report.

The 24-hour urine samples, preserved with approximately 5 gm. of benzoic acid, were acidified with 3 ml. of concentrated sulfuric acid per liter of urine to bring the pH to approximately 1.0. Acidified samples settled overnight and sedimentary solids were removed by filtration through six to eight layers of filter paper.

An anion exchange mat was prepared using stock asbestos-silver chloride suspension. The stock suspension was made by combining, in order, 1,465 ml. of distilled water, 5 ml. concentrated sulfuric acid, 25 ml. of 1.25 N. hydrochloric acid and 30 gm. of Gooch Asbestos. To this 3.75 gm. of silver nitrate, dissolved in 5 ml. of water, was added dropwise with constant stirring.

Asbestos mats were prepared by assembling an 80-mm. medium sintered glass filter funnel in a 2-liter filter flask. A filter paper, just large enough to cover the sinter, was put in place and 100 ml. of the freshly prepared stock asbestos suspension was added. It was found that a battery of 12 mats could be made from each lot of the anion exchange preparation and operated on a manifold. It was necessary to shake the asbestos suspension frequently in order to mix it sufficiently to insure a mat of uniform thickness. A filter paper was placed over the mat and suction was applied. When most of the liquid was drained from the mat, it was washed with two 25-ml. portions of 0.1 N. sulfuric acid. Care was taken never to allow the mat to run dry since this was found to cause channeling within the mat.

When most of the second portion of wash liquid was drawn through the mat, the urine was carefully poured to avoid disturbing the edges of the mat. Suction was regulated to a rate of flow not exceeding 1 liter per 10 minutes. When a few milliliters of urine remained, the mat was washed with two 25-ml. portions of 0.1 N. sulfuric acid and the mat was sucked dry under full vacuum. The top filter paper was removed and discarded. The mat was then stripped from the filter funnel with a spatula and placed in a Petri dish.

[redacted]

Frequent use caused the funnels to clog and made control of filtration rate difficult. Haemosol was satisfactory for cleaning in moderate cases and 6 N. sulfuric acid was used for the more difficult.

Recovery studies of a series of mats indicated that the anion exchange process removed 90 per cent, plus or minus 10 per cent, of known amounts of iodine from the urine. This is of the same magnitude of recovery of iodine reported by Purves (1). Studies to determine the extent of self-absorption for beta radiation by the exchange mat were carried out. These demonstrated that approximately 80 per cent of the iodine was exchanged in the upper 10 per cent of the mat having a density of 4 mg. per sq. cm.

Special care is necessary to avoid contamination of any laboratory equipment. Further, the mats must be thoroughly rinsed in order to insure that all the normal potassium-40 has been removed. It is suggested that constant background controls be run throughout the procedure. A considerable portion of the controls were not completely free of activity. This could have been due to reactor effluents at Hanford and Oak Ridge. Since it was unknown whether these sources or technical factors within the laboratory were responsible for the observed counts, the pre-test determinations are not included. During the test series all urine samples were handled by the same technical process and personnel. No radioactive substances were allowed to enter the processing laboratory.

When the volume of urine from a single individual 24-hour sample was below 750 ml., creatinine determinations were made. The normal creatinine for a 24-hour specimen is 0.8 to 1.8 mg.

Counting

The beta activity of the ion exchange mats was measured with large (1 1/2 x 6 1/4 inches active volume) cylindrical thin-wall flow-type Geiger counters (2). These counters were shielded from cosmic radiation by means of a large iron shield (8 1/2" thick on top, 6 1/4" on the sides and 4 1/4" on bottom) and a bundle of cosmic ray counters operating in anticoincidence with the sample counters. This type of shielding is identical with that used in carbon-14 dating work (3). The background for these counters when fully shielded in this laboratory is 2.5 to 3 counts per minute. Samples were positioned in close

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(1) Purves, H. D.: Nature 169:111, 1952.

(2) These counters are similar to the type described by T. T. Sugihara, R. Wolfgang and W. F. Libby -- Rev. Sci. Instruments 24-7:511, 1953.

(3) Anderson, E. C., Anderson, J. R., and Libby, W. F.: Rev. Sci. Instruments 22-4:225, 1951.

[redacted]

cylindrical geometry with respect to the counters by the use of lucite half cylinders. Over-all efficiency for iodine-131 beta particles in the mats is 32 per cent. In order to establish the identity of the radioactivity of samples appreciably above background, decay and absorption curves were determined.

Conversion of Observed Counts to Absolute Disintegrations

The factors which must be taken into account in converting counts to disintegrations are (a) geometrical efficiency, (b) absorption of the beta particles in the counter wall, and (c) distribution of activity within the sample and self-absorption of the sample.

The geometry factor for the sample-counter arrangement used is 2.65 and the geometrical efficiency is 37.7 per cent. This was determined experimentally using the natural K-40 activity of potassium chloride as a standard.

The counter/wall/absorption correction factor is 1.08. This was calculated from the experimentally determined absorption coefficient for iodine-131 beta radiation and from the known counter wall thickness.

The distribution and self-absorption correction factor (1.1) was calculated from experimental data. The distribution of radioactive atoms within the asbestos mats was determined by penetration and retention studies. The self-absorption was calculated after the non-uniform distribution was known.

Combining these three factors, one obtains a grand conversion factor of 3.15, Thus:

$$2.2 \times 10^6 \text{ dpm} = 1 \text{ microcurie}$$

$$1 \text{ cpm} = 3.15 \text{ dpm} =$$

$$\frac{3.15}{2.2 \times 10^6} \text{ microcuries} = 1.43 \times 10^{-6} \text{ microcuries}$$

[redacted]

[redacted]

APPENDIX B-2

COUNTING OF THYROID TISSUES

After recording total weight of the thyroid glands, histologic sections were removed at the Armed Forces Institute of Pathology. The balance of the gland was processed for counting in this laboratory. The total thyroid tissue was minced and dried over sulfuric acid for 24 hours. The exsiccated tissue was then counted directly for beta radiation in the same counters used for counting mats. This was reasonably efficient because of the large sample area accommodated by the counter. The samples too active for the low-level counter were counted with a well-type scintillation counter.

[redacted]

[redacted]

APPENDIX B-3

EXTRACTION AND COUNTING OF URINARY STRONTIUM-90

The 24-hour urine samples for each week from a station were pooled and acidified to pH 0.5 with hydrochloric acid. Two grams of strontium nitrate and 30 grams of calcium nitrate were added as carrier, together with 25 grams of oxalic acid. The sample was heated to 80 to 90° C. Oxalate salts were precipitated by adding sufficient concentrated ammonium hydroxide to approximate pH 8.0 and the sample was allowed to stand overnight.

The following day most of the supernatant fluid was carefully siphoned off and the remainder filtered by suction through a porcelain Buchner funnel containing Whatman No. 42 filter paper. The precipitate was pulled dry and washed with dilute ammonium oxalate/oxalic acid solution (2 gm. ammonium oxalate per 100 ml. of 1 per cent oxalic acid). The precipitate was dried on the funnel and paper was ignited overnight at 900° C in a porcelain crucible by an electric muffle furnace.

The mixed oxides were weighed and dissolved in concentrated hydrochloric acid using approximately 3 ml. of acid per gram of oxide. The acid solution was diluted to approximately 3 N., then filtered if not clear.

One ml. of 85 per cent phosphoric acid per gram of oxide and 0.3070 gram of yttrium oxide,* dissolved in dilute hydrochloric acid, were added to the solution. The solution was then heated to 80 to 90° C and concentrated ammonium hydroxide was added slowly with vigorous stirring to redissolve any calcium phosphate which might be coprecipitated with yttrium phosphate. The base was added until slight opalescence was produced, and the solution was digested until the precipitate (yttrium phosphate) coagulated. Ten ml. of 2 N. ammonium hydroxide was added per milliliter of sample solution and the solution was digested for 15 minutes. The precipitate was then recovered using Whatman No. 42 filter paper in a porcelain Buchner funnel.

The precipitate was dissolved from the funnel by two 10-ml. portions of hot 2 N. hydrochloric acid followed with a wash of distilled water.

The combined solution and wash was diluted to approximately 400 ml. Five ml. of 85 per cent phosphoric acid was added and the solution was

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*Procured from Ames Laboratory, Atomic Energy Commission, Ames, Iowa. This product required additional purification to make it satisfactory for low-level activity counting. Purification procedure used was that developed by Operation Sunshine (L-1005).

[redacted]

heated to 80 to 90° C. Concentrated ammonium hydroxide was added until the solution was faintly opalescent. The precipitate (yttrium phosphate) was coagulated by digestion and 50 to 75 ml. of 2 N. ammonium hydroxide was added in small portions until the pH just changed from one to two as indicated by Hydrion paper. After a 15-minute digestion, the solution was filtered as previously described.

The precipitate was pulled dry, transferred quantitatively to a porcelain crucible and ignited by a gas-oxygen flame, while gently bleeding oxygen into the top of the crucible. The ignited sample was then weighed, ground to a fine powder, and mounted on a half-cylinder of bakelite for counting using agar solution (0.1 per cent) and 95 per cent ethanol as mounting agents.

The filtrate from the final precipitation was alkalinized to approximately pH 8.0 by the addition of ammonium hydroxide. The precipitate was separated by centrifugation, the supernatant decanted, and the precipitate dissolved in a few milliliters of hot (70° C) 6 N. hydrochloric acid. This solution was combined with the filtrate from the first yttrium phosphate precipitation. This solution, containing strontium-90, was saved for subsequent "milkings" for the daughter yttrium.

It was noted from the decay curves of the single precipitation that isotopes other than yttrium-90 were present. After a period of 2 weeks to allow equilibrium between strontium-90 and yttrium-90 to be approached, the solution was again processed to remove the yttrium. The only variation of the process was that preliminary procedures through the first addition of phosphoric acid were not necessary. From the addition of yttrium oxide carrier the process was as outlined above. In the event a fourth milking was deemed necessary, an excess of phosphate was assured by adding phosphoric acid.

<u>Counting for Strontium-90</u>

Yttrium-90 was separated from its parent strontium as outlined in the chemical procedures. Since the strontium-90 activity is equal to that of yttrium-90 at the moment of separation, the radioactivity of the strontium-90 was determined by counting the radioactive yttrium-90 and corrected to time of separation.

The yttrium phosphate sample from the chemical procedure was mounted (as previously described) on a small half-cylinder of bakelite. The cylinder holds the sample in close geometry with respect to the small cylindrical flow counter.

The over-all efficiency for the yttrium-90 activity is 25 per cent. For conversion of the observed counts to disintegrations per minute, the area and density of each sample as mounted in the cylinder were determined to correct for self-absorption and geometry. In all cases the decay of the sample was followed for sufficient time to establish the slope. The identity of yttrium was further confirmed by absorption studies.

[redacted]

APPENDIX C-1

THYROIDAL I^{131} KINETICS
Accumulation and Total Dose for Individual Exposed
Throughout the Test Series at a Given Station

Introduction

Some estimation of total or integrated iodine-131 accumulation seemed indicated for at least two reasons:

a. Whereas the relative hazard of this fission isotope has been assumed to be small, the magnitude of activity prevailing in man from the detonation of test devices has not been precisely defined.

b. The possibility of relating iodine-131 to strontium-90 activity during exposure to fission products makes a detailed understanding of iodine-131 a matter of considerable importance (See Appendix C-2).

It is obvious that an exact figure for thyroidal iodine-131 accumulation (critical organ activity) will not be forthcoming from a measure of 24-hour urine specimens at weekly intervals. On the other hand, it was thought that the assumptions and calculations outlined below should lead one to an integrated activity estimate which may be considered reasonable, based on available data.

The urinary excretion of iodine is directly related to the blood; the latter reflecting intake when removal rates by thyroid and kidneys are considered. These processes are relatively rapid in that excretion activity reflects exposure within the same 24-hour period. The fluctuating urinary values and their correlation with cloud appearance indicate that men at a given station were subjected to correspondingly fluctuating iodine exposures throughout the test series. Peak values recorded could have been higher on days preceding or following the collection date. Moreover, in most instances the true peak excretion values will be followed within subsequent days by a significant decline in activity -- since the intake is reduced by the combined effect of weather conditions and decay. This reasoning led to a simple average of urinary excretion data, which implies a constant (average) intake.

Compartment System Model

Compartment system models have found considerable utility in studying iodine metabolism (1, 2) -- especially with respect to iodide kinetics. Established data from clinical studies allow us to assume a rather simplified model which appears adequate for present purposes.

(1) Riggs, D. S.: Quantitative Aspects of Iodine Metabolism in Man. Pharmacological Reviews 4:284-370, 1952.

(2) Oddie, T. H., Meschan, I., and Wortham, J.: Thyroid Function Assay with Radioiodine (1955).

[redacted]

[redacted]

Assumptions:

1. Three compartments for iodine-131 (iodide), namely,

a. Blood (and body fluids making up the volume of distribution for iodide)

b. Thyroid

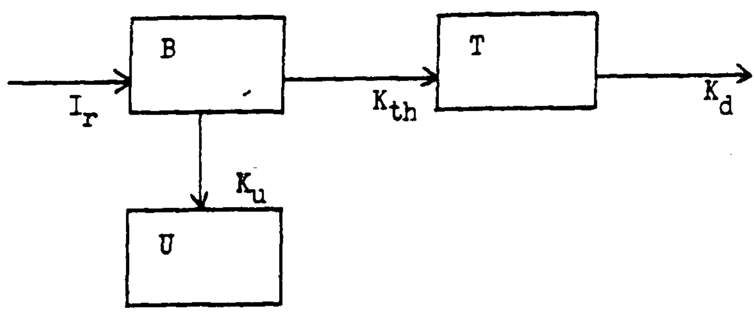
c. Urine

2. A constant intake prevails (as assumed above).

3. The system is in equilibrium such that the blood level remains constant (calculated from average urinary excretion).

4. All the iodine-131 transferred to the gland remains fixed and the thyroidal activity decreases by decay only. Hormone secretion and reutilization of iodine-131 is neglected. This results in a conservative (slightly higher) value for accumulated activity.

The model follows:



I_r = rate of intake (dpm t^{-1})

B = concentration in compartment of blood (and volume of distribution of iodide) (dpm/L)

B_o = B at time $t = o$

T = total activity transferred from blood to thyroid at time t (dpm)

U = total activity excreted into urine at time t (dpm)

K_u = renal clearance rate constant (L/d)

K_{th} = thyroid transfer rate constant (L/d)

K_d = decay rate constant for iodine-131 (t^{-1})

dpm = disintegrations per minute

D = disintegrations (absolute number of betas)

t = time (days)

L = unit volume (liters)

[redacted]

[redacted]

$$\frac{dT}{dt} = K_{th}\,B - K_d\,T$$

where $B = B_o$ = constant

from
$$\int_0^T \frac{-K_d\,dt}{K_{th}\,B_o - K_d T} = -K_d \int_0^t dt$$

$$T = \frac{K_{th}}{K_d}\,B_o \left[1 - e^{-K_d t}\right] \qquad (1)$$

B_o is found from the following

$$U = K_u\,B_o$$

$$B_o = \frac{U}{K_u}$$

$$T = \frac{K_{th}}{K_d}\,\frac{(U)}{(K_u)} \left[1 - e^{-K_d T}\right] \qquad (2)$$

This equation gives the activity within the thyroid at time t.

Calculation of Thyroidal Accumulation and Integrated Dose

During the period of fallout the total or integrated thyroidal exposure is found from (1):

$$\sum_{t=o}^{t} D = \int_o^t \frac{K_t}{K_d}\,B_o\,(1 - e^{-K_d t})$$

$$= \frac{K_{th}}{K_d}\,B_o \left[t - \frac{1}{K_d}\,(1 - e^{-K_d t})\right] \qquad (3)$$

where $\sum_{t=o}^{t} D$ = total number of disintegrations (betas) to which thyroid is exposed during time $t = o$ to $t = t$

[redacted]

Choice of Constants and Numerical Calculation for Fitzsimons Army Hospital (Denver)

$K_u = 46$ (L/d), (3)

$K_t = 23$ (L/d) (4)

$K_d = 0.08453$ (d^{-1})

($T_{\frac{1}{2}} = 8.2d$)

$$U_{average} = U = \frac{\sum Um}{\text{Number of specimens}} = 70 \text{ (dpm/d)}$$

No specimens were obtained on two occasions. Thus for the 14-week period, 12 specimens were averaged (Um = measured U's).

The activity within the thyroid as a function of time using equation (2) is given in Figure C-1, from t = o to t = 100 days.

After 100 days the activity will decay according to:

$$T = T_o \quad e^{-K_d t} \qquad (4)$$

This decay phase is shown following t = 100 days in Figure C-1.

The integrated exposure (total number of disintegrations) from equation (3), for the constants as given:

$$\sum_{t = o}^{t = 100\ d} D = 36{,}726 \text{ (dpm) (days)}$$

$$= (36{,}726) \quad (1{,}440)$$

$$= 5.29 \times 10^7 \text{ disintegrations}$$

During the decay phase after 100 days (no further exposure)

$$\sum_{t = 100}^{t = \infty} D = T_o \int_{t' = o}^{t' = \infty} e^{-K_d t'} \quad \text{(where } t' = \theta = t = 100 \text{ days)}$$

$$= \frac{T_o}{K_d} \qquad (5)$$

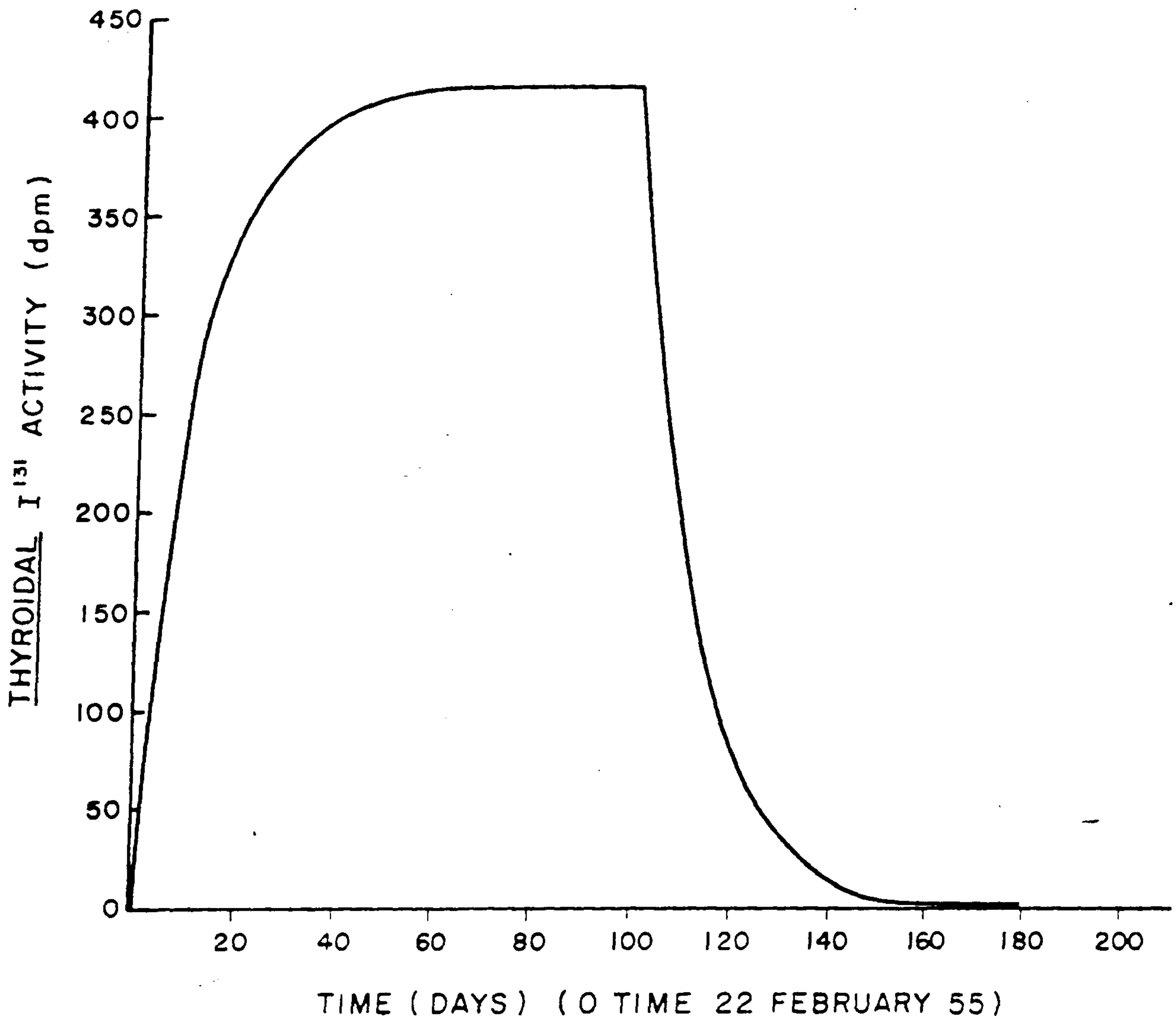
(3) Average value noted by Riggs (ibid).

(4) Ingbar, S. H.: Simultaneous Measurement of the Iodide-Concentrating and Protein-Binding Capacities of the Normal and Hyperfunctioning Human Thyroid Gland. J. Clin. Endo. and Metab. 2:238-264, 1955.

[redacted]

FIG C-1

THYROIDAL ACCUMULATION AND DECAY OF I^{131}



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This interval from t = 100 to t = oo contributes a relatively small additional exposure, namely,

$$\sum_{t = 100\text{ d}}^{t = \infty} D = 0.71 \times 10^{7} \text{ disintegrations}$$

Hence the total "average" thyroidal exposure to iodine-131 betas for an individual at Fitzsimons is

$$\sum_{t = o}^{t = \infty} D = \sum_{t = o}^{t = 100} D + \sum_{t = 100}^{t = \infty} D$$

$$= 6.00 \times 10^{7} \text{ disintegrations}$$

<u>Thyroid Dose (rep) and Comparison with Iodine-131 Activities Used Clinically</u>

The dose delivered to the thyroid was calculated from:

$$\text{Total Dose} = \sum \frac{D}{W} \quad \bar{E}_B \quad \left(\frac{1}{5.25}\right) 10^{-13} \qquad (5) \qquad (6)$$

where D = total disintegrations (betas)

W = weight of gland (gm.) = 20 (gm.)

$\bar{E}_B$ = average beta energy (ev)

= 0.20×10^{6} (ev)

Total Dose = 0.011 rep

This may be compared with the thyroid exposure from a 10-microcurie tracer dose of iodine-131 calculated from equations (5) and (6), assuming a 33 per cent uptake by the gland. In this situation about 1.3×10^{11} disintegrations or 24 rep are delivered to the thyroid. Thus the "<u>average</u>" <u>calculated</u> thyroidal exposure at Denver for the test series was about 4.5×10^{-4} that delivered by a 10-microcurie (tracer) dose of iodine-131.

(5) Sirie, W. E.: Isotopic Tracers and Nuclear Radiations, pp. 417-418, McGraw-Hill Book Co., Inc., New York, 1949.

[redacted]

[redacted]

APPENDIX C-2

RELATIONSHIP OF URINARY
IODINE-131 AND STRONTIUM-90 ACTIVITIES (dpm's)

A precise functional relationship cannot be derived from the iodine-131 and strontium-90 activities in the specimens measured (Table 1). However, some comments as to the apparent correlation are in order.

Table 1

Iodine-131 and Strontium-90 Data

Station	Week	Decay* time (days)	I^{131}	Fraction of I^{131} Corrected	No. Spec.	Corr. I^{131}	Pooled Corr. I^{131}	Strontium	I^{131}/Sr^{90}
O	5	11 1/2	1,205	1	10	3,205			
	9	4 1/2	1,181	1	9	1,732			
	10	11 1/2	1,066	1	9	2,835	15,530	29.92	519
	13	12 1/2	1,353	1	9	3,922			
	14	9 1/2	1,021	1/2	9	3,835			
		19 1/2		1/2					
B	10	11 1/2	1,855	1	9	4.934			
	13	2 1/2	666	1	6	824	7,803	13.13	594
	14	9 1/2	910	1	6	2.045			
M	13	2 1/2	891	1	7	1,103			
	14	9 1/2	1,739	1	6	3,908	5,011	8.46	592
X	8	4 1/2	2,525	1	8	3,702	3,702	8.48	437
		12 1/2		1/4		1,315			
X	13	2 1/2	794	3/4	3		3,425	2.06	1,662
	14	9 1/2	938	1	4	2,110			
N	14	9 1/2	1,028	1	2	2,310			
B	4	8 1/2	818	1	11	1,687	1,541	2.3	670
X	3	1 1/2	551	1	10	626			

*Iodine decay time (days) determined by evaluation of Figures 4 to 9. Cloud position over station was related to a particular shot and yield.

First, one may calculate the relative activities (measurable as dpm) of iodine-131 and strontium-90 if present in a specimen in equal numbers of atoms.

I = iodine-131 activity (dpm)
S = strontium-90 (yttrium-90) activity (dpm)
N = number of iodine-131 atoms
M = number of strontium-90 atoms
t = time (days)

[redacted]

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Then

$$I = \frac{dN}{dt} = -k_i N$$

$$S = \frac{dM}{dt} = -k_s M$$

Where k_i and k_s are the respective decay constants.

$$\frac{I}{S} = \frac{-k_i N}{-k_s M} = \frac{k_i}{k_s} = C$$

Thus $I = CS$

Where C is a proportionality constant relating the activities.

The actual value of C is found from the equation relating half time to decay constant for a specific isotope.

For iodine and strontium:

$$k_i = \frac{0.693}{8.2} \quad \text{and} \quad k_s = \frac{0.693}{25(365)}$$

Where 8.2 and 25(365) are respective half lives in days.

Whence:

$$C = 1.1 \times 10^3$$

From the above one would expect about 1.1×10^3 iodine-131 (dpm) for each strontium (dpm), from samples containing equal iodine-131 and strontium-90 atoms.

Next the fission yields for each isotope are considered; namely, about 1 gram (or essentially equal weights) of each per kiloton. However, this implies:

$$\frac{\dfrac{\text{Wt. } Sr^{90}}{90}}{\dfrac{\text{Wt. } I^{131}}{131}} = \frac{131}{90} = 1.46$$

atoms of strontium-90 per iodine-131 atom in the fission products.

Hence, if equal masses of the isotopes were present,

$$I = \left(\frac{1}{1.46}\right) CS \qquad (2)$$

$$= 750\ S$$

would relate the activities, at a time just following detonation.

If we assume no physical fractionation from site of fission to collection station, the above argument holds, except that a significant time may have elapsed for the decay of iodine-131. The number of atoms remaining being:

$$N_t = N\ e^{-k_i t}$$

Equation (1) becomes:

$$C = \frac{-k_i\ N_t}{-k_s\ M} = \frac{k_i\ N\ e^{-k_i t}}{k_s\ M}$$

$$= \frac{k_i}{k_s}\ e^{-k_i t}$$

And equation (2) becomes:

$$I = 750\ e^{-k_i t}\ S \qquad (3)$$

Provided the strontium-90 at a given station was metabolically available in essentially the same amounts as iodine-131, and that urinary excretion kinetics are similar, equation (3) should represent intake activities. This approach provides a working hypothesis that allows some comparison of the observed urinary iodine and strontium values. Figure 12 represents iodine-131 versus strontium-90 where the iodine-131 activity has been corrected to time of fission. The slope of the resulting line is 576 (dpm I^{131} per dpm Sr^{90}).

Implicit in the close agreement of the calculated iodine-131 versus strontium-90 activities with those observed (during Operation Teapot) is the contention that strontium-90 was essentially as available and indeed taken into man in amounts comparable to iodine-131 on an acute exposure basis.

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APPENDIX C-3

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ESTIMATION OF TOTAL URINARY EXCRETION OF STRONTIUM-90

For the three stations (B, M and O, Fig. 1) at a significant distance from the test site, some estimate of total strontium-90 excretion was desired. The same general arguments utilized for averaging weekly iodine-131 values apply here. However, since specimens chosen for strontium-90 determination were probably more active than a true a average specimen, the resulting total excretion value might be considered near maximum for these stations.

The following formula was utilized for calculating the "average" strontium-90 excretion for a single individual throughout the final 100 days of the test series.

"Average" Total Strontium-90 Excretion per Individual

$$\text{(in microcuries)} = \left[\frac{\text{dpm (of pooled specimens)} \times 100\ \text{(days)}}{\text{(no. of weeks pooled) (no. individuals)}}\right] \left[\frac{1}{2.2 \times 10^{6}\ \text{dpm per microcurie}}\right]$$

This relation gave the following values:

Station B: 24×10^{-6} microcuries

Station M: 30×10^{-6} microcuries

Station O: 30×10^{-6} microcuries

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